

Report on the Comparison of the Scan Strategies Employed by the Patrick Air Force Base WSR-74C/McGill Radar and the NWS Melbourne WSR-88D Radar

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Executive Summary

The objective of this investigation is to determine whether the current standard WSR-88D radar (NEXRAD) scan strategies permit the use of the Melbourne WSR-88D to perform the essential functions now performed by the Patrick Air Force Base (PAFB) WSR-74C / McGill radar for evaluating Shuttle weather Flight Rules (FR) and Launch Commit Criteria (LCC). To meet this objective, the investigation compared the beam coverage patterns of the WSR-74C / McGill radar located at PAFB and the WSR-88D radar located at the Melbourne National Weather Service (NWS) Office over the area of concern for weather FR and LCC evaluations. The analysis focused on beam coverage within four vertical 74 km radius cylinders (1 to 4 km above ground level (AGL), 4 to 8 km AGL, 8 to 12 km AGL, and 1 to 12 km AGL) centered on Kennedy Space Center (KSC) Launch Complex 39A. The PAFB WSR-74C / McGill radar is approximately 17 km north-northeast of the Melbourne WSR-88D radar.

This analysis has shown that effective beam coverage is a function of both scan strategy and distance from the radar to the point of interest. For example, the results indicate that the advantages inherent in the scan strategy of the McGill radar (more elevation scans and higher elevation scans) relative to the WSR-88D are offset by the preferred location of the WSR-88D relative to the McGill radar and KSC / Cape Canaveral Air Station (CCAS). Indeed, the beam coverage of the WSR-88D exceeds the beam coverage of the McGill radar over most of the KSC / CCAS area by 5 to 20% in the 4 to 8 km layer, by 5 to 10% in the 8 to 12 km layer, and by 5 to 10% in the 1 to 12 km layer.

The beam coverage of the scan strategy employed by the McGill radar and the Volume Coverage Pattern (VCP) 11 scan strategy of the WSR-88D exceeds 70% in the 1 to 4 km, 4 to 8 km, and 1 to 12 km layers for most of the area of concern. However, the extent of good beam coverage (coverage equal to or greater than 70%) is less in the 8 to 12 km layer for both radars because of the gaps in radar beam coverage in the higher elevation scans. In fact, neither radar provides good beam coverage in the 8 to 12 km layer over most of the KSC / CCAS area.

The difference in percent of the atmosphere sampled between the two radars is less than 10% for more than half of the area of concern for all four layers. However, there are significant differences in beam coverage between the two radars in the near vicinity of the radars. This results from the cone of silence directly above and near the radars which is a function of the radar's scan strategy. This limitation is slightly more severe for the WSR-88D since the highest elevation angle of VCP 11 is 19.51° whereas the highest elevation angle of the McGill scan strategy is 35.97° .

The beam coverage of the WSR-88D using VCP 11 located at the Melbourne NWS Office is comparable (difference in percent of the atmosphere sampled between the two radars is 10% or less) within the area of concern to the beam coverage of the WSR-74C / McGill radar located at PAFB. Both radars provide good beam coverage over much of the atmospheric region of concern. In addition, both radars provide poor beam coverage (coverage less than 50%) over limited regions near the radars due to the radars' cone of silence and gaps in coverage within the higher elevation scans. Based on scan strategy alone, the WSR-88D radar could be used to perform the essential functions now performed by the PAFB WSR-74C / McGill radar for evaluating Shuttle weather FR and LCC. Other radar characteristics may, however, affect the decision as to which radar to use in a given case.

1.0 Introduction

1.1 Purpose of the Report

This report documents the results of the Applied Meteorology Unit's (AMU) NEXRAD (WSR-88D) / McGill Inter-evaluation subtask. The objective of the subtask is to determine whether the current standard NEXRAD scan strategies permit the use of the NEXRAD to perform the essential functions now performed by the Patrick Air Force Base (PAFB) WSR-74C / McGill radar for evaluating Shuttle weather Flight Rules (FR) and Launch Commit Criteria (LCC). The report also highlights other important characteristics of the radars which impact the quality and availability of products for Shuttle FR and LCC evaluations. In addition, the report outlines the procedure for requesting a modification to an existing scan strategy or creation of a new scan strategy for the WSR-88D.

1.2 Organization of the Report

This report is divided into five major sections. Section 1 provides a brief description of the objective of the investigation and background on the weather radars and the motivation for the investigation. Section 2 describes how the two weather radars are currently used for Shuttle FR and LCC evaluations. The results of the scan strategy analysis are presented in Section 3. A list of issues and concerns is presented in Section 4 and a summary and list of recommendations are included in Section 5.

1.3 Radar Background

The PAFB WSR-74C / McGill radar consists of a WSR-74C radar controlled by a Volumetric Scan Processor developed by McGill University. The WSR-74C radar is a C-band weather radar which is capable of detecting the presence and intensity of precipitation within a 370 km (200 nm) radius of PAFB. It was installed at PAFB in March 1984. In 1987 the radar system was modified to include the McGill Volumetric Scan Processor. This subsystem controls the antenna, raising it through 24 different elevation angles in a five minute period and collects, stores and processes the three-dimensional reflectivity data. Subsystem display workstations are located in the Range Weather Operations (RWO) and the AMU in the Range Operations Control Center (ROCC) at CCAS. The workstations can produce and display a number of user selected products including Constant Altitude Plan Position Indicator (CAPPI) reflectivity products, reflectivity vertical cross-sections, and echo-top reflectivity products.

The WSR-88D radar is the new operational meteorological weather radar replacing the non-Doppler meteorological radars of the NWS and the Air Force. The WSR-88D radar represents a quantum leap in engineering technology and in meteorological measurements from the earlier weather radars. As a fully coherent "Doppler" radar, the WSR-88D provides not only information on the location, distribution, and intensity of precipitation, but also provides measurements of the radial component of motion of the scatterers and the dispersion of radial velocities in the sampling volume.

The WSR-88D radar system consists of three primary components:

- A radar composed of transmitter, receiver, antenna and associated support circuitry,

- Dedicated signal processors which produce estimates of reflectivity intensity, radial velocity, and spectrum width, and
- Data analysis and display subsystems which produce meteorological products and displays.

A WSR-88D radar became operational at the Melbourne NWS Office in the fall of 1991 and was commissioned in March 1994. Operational display workstations (Principal User Processors (PUP)) with dedicated communications lines to the radar system are located in the Melbourne NWS Office, the RWO in the ROCC at CCAS and the Spaceflight Meteorology Group (SMG) at Johnson Space Center. In addition to basic reflectivity intensity and velocity products, these advanced workstations provide information about the existence of severe storm characteristics such as mesocyclones and hail, estimates of future storm motion, and estimates of the vertical profile of the horizontal wind.

Currently, RWO and SMG weather forecasters use various products from the two weather radars to support evaluation of a number of Shuttle weather FR and LCC. Specifically, reflectivity intensity estimates from the weather radars are used to determine the location, distribution, movement, thickness, intensity, and tendency of rain showers, cumulus clouds, thunderstorms, anvils, and debris clouds which are near the launch / landing site or near the projected flight path of the vehicle.

The PAFB WSR-74C / McGill radar is a highly flexible weather radar which is controlled and operated by the Air Force with the primary function of supporting Eastern Range (ER) / NASA operations. However, the WSR-74C / McGill radar is also a 10 year old radar based on 20 to 30 year old technology and is a "one-of-a-kind" system because of the McGill Volumetric Scan Processor. All maintenance and operations costs for the radar are funded by the ER and NASA. Conversely, the Melbourne WSR-88D radar is less than 5 years old and is based on 10 year old technology. The majority of the operations and maintenance costs of the system are funded by the Air Force and the NWS through the Joint Systems Program Office. The system also has improved sensitivity (clear-air mode) and Doppler capability. However, the Unit Radar Committee, composed of Air Force, NWS and Federal Aviation Administration (FAA) representatives, controls daily operation of the Melbourne WSR-88D radar and the Operational Support Facility provides configuration control of the system. Furthermore, the radar supports not only the space launch / landing community but also the NWS and FAA requirements.

The motivation for the weather radar scan strategy comparison is derived from the cost versus benefit analysis of continuing to maintain and operate the WSR-74C / McGill radar relative to using the Melbourne WSR-88D radar for Shuttle weather FR and LCC evaluations. This investigation is one component of the complex cost versus benefit analysis of the two radar systems.

2.0 Use of Weather Radars for Flight Rule and Launch Commit Criteria Evaluation

Products from the two weather radars are currently used by RWO and SMG weather forecasters to support evaluation of a number of Shuttle weather FR and LCC. Specifically, the weather radars are used to evaluate rain showers, cumulus clouds, thunderstorms, anvils, and debris clouds which are near the launch / landing site or near the projected flight path of the vehicle. Although each weather phenomena has unique proximity requirements relative to the launch / landing site or the projected flight path (see Table 2.1 and Figure 2.1), RWO and SMG forecasters are generally concerned with the presence of any weather phenomena within an 74 km (40 nautical mile) radius cylinder from the launch / landing site. The 74 km radius cylinder encompasses the proximity requirements of all the weather FR and LCC plus provides for a buffer zone for phenomena close to but not within the critical region.

The vertical extent of the atmosphere examined for FR and LCC evaluations varies depending upon which weather phenomenon is being investigated. The vertical regions of interest are as follows:

Rain Showers and Cumulus Clouds	1 to 4 km Above Ground Level (AGL)
Thunderstorms and Lightning Potential	4 to 8 km AGL
Thunderstorm Anvils and Debris Clouds	8 to 12 km AGL.

An additional item which is not part of the weather FR and LCC included in Table 2.1, but which is important to the scan strategy comparison, is a proposed Vertically Summed Reflectivity at 0°C Isotherm (VSR0C) LCC. The purpose of the VSR0C is to estimate the triggered lightning potential of layered clouds. The most recently proposed definition of the VSR0C is the sum of the McGill radar reflectivities within a vertical column from the level near the 0°C isotherm to the highest sampled level. For clouds of concern, the 4 to 8 km AGL layer will have the most impact on VSR0C calculations.

The 74 km radius cylinder and the three aforementioned vertical layers plus one vertical layer which encompasses the first three (i.e., 1 to 12 km AGL) form the basic sampling regions for the scan strategy comparisons.

**Table 2.1. Shuttle Weather Flight Rules and
Launch Commit Criteria Evaluated By Radars**

Weather Flight Rules and Launch Commit Criteria	Operation	
	Launch	Deorbit
Clouds Can not fly through cumulus clouds with tops above +5°C isotherm Can not fly through or within 5 nm of cumulus clouds with tops above -10°C isotherm Can not fly through or within 10 nm of cumulus clouds with tops above -20°C isotherm Can not fly through a vertically continuous cloud layer which is 4500 ft thick or greater, or any part of a cloud which is within the 0°C to -20°C isotherm levels Can not fly through any cloud that has a top above the 0°C isotherm level and is associated with disturbed weather (moderate or greater precipitation)	X X	
Thunderstorm Can not fly through or within 10 nm of the nearest edge of any thunderstorm or its anvil Can not fly through or within 20 nm of precipitation, lightning, or thunderstorm (including anvil) at the landing site or within 10 nm laterally and 2 nm vertically to the approach path to a range of 30 nm Can not fly through or within 30 nm of precipitation, lightning, or thunderstorm (including anvil) at the landing site or within 10 nm laterally and 2 nm vertically to the approach path to a range of 30 nm After deorbit burn, a distance of 5 nm horizontally and 2 nm vertically must be maintained from all thunderstorms, anvils, and any other convective clouds (rain showers with tops above -10°C isotherm)	X X	 X X
Anvil Can not fly through thunderstorm debris clouds, within 5 nm of a debris cloud not monitored by the ground-based field mills or any debris cloud producing radar returns greater than 10 dBz Opaque detached anvils less than 3 hours old must not be within 20 nm of launch / landing site, nor within 10 nm of approach path out to 30 nm	X X	 X
Precipitation Can not launch if precipitation or minimum discernible echo is within the projected path	X	
Lightning Can not launch if lightning is detected within 10 nm of pad or projected path within the past 30 minutes, unless the condition that produced the lightning has moved greater than 10 nm away from pad or path	X	

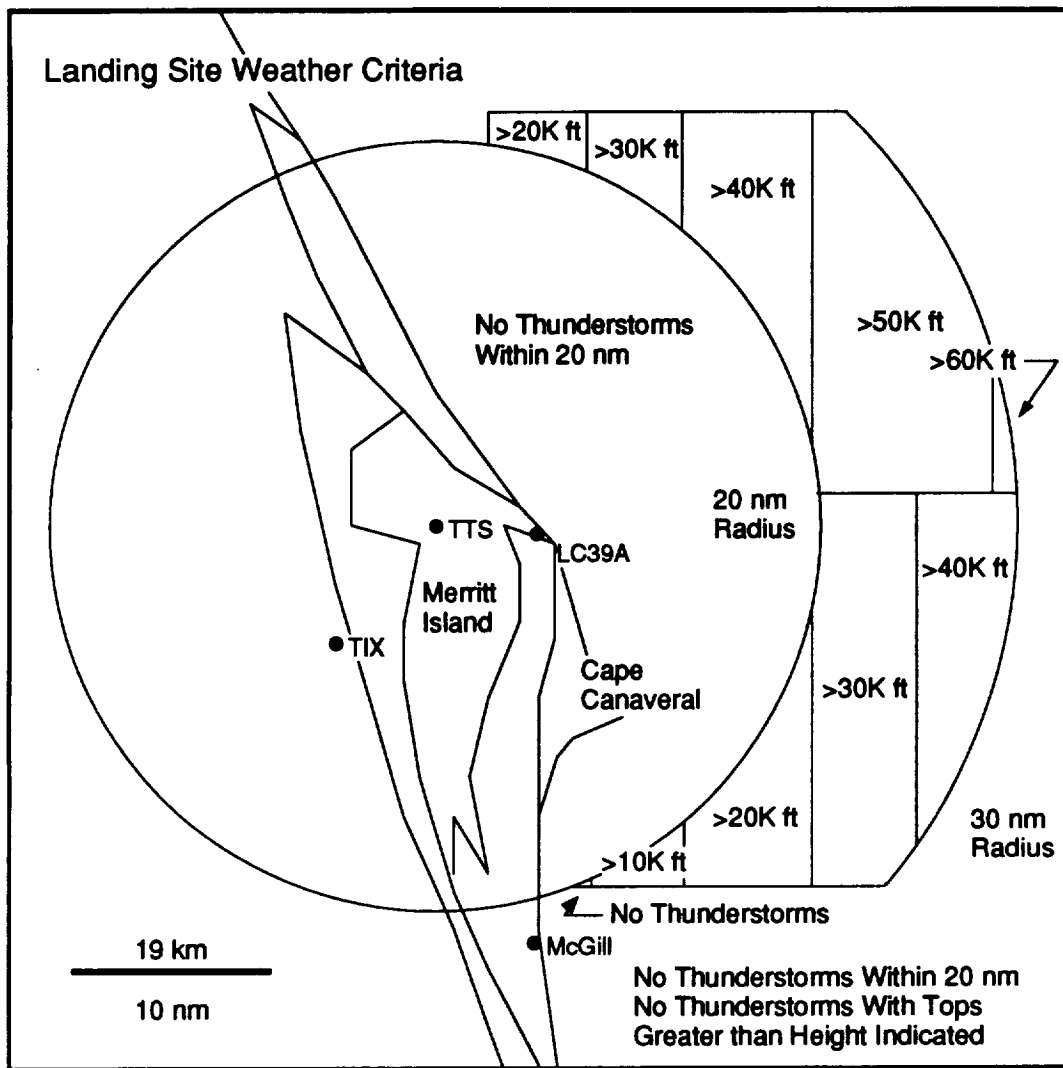


Figure 2.1. Illustration of the thunderstorm proximity requirements relative to the Shuttle landing site (Johnson Space Center, 1992).

3.0 Scan Strategy Analysis

3.1 Analysis Procedures

The scan strategy analysis is based on comparisons of the fraction of the atmosphere illuminated by the radars which is a function of number of elevation scans and angles, beam width, and distance from the radar. The fraction of a vertical cross-section of the atmosphere illuminated by the radars is determined by estimating the radar beam paths using the Effective Earth Radius Model (Section 3.1.1) and the radars' elevation angles and beam widths (Figure 3.1). The analysis focuses on the four vertical layers defined in Section 2. The four vertical layers are

- 1 to 4 km AGL,
- 4 to 8 km AGL,
- 8 to 12 km AGL, and
- 1 to 12 km AGL.

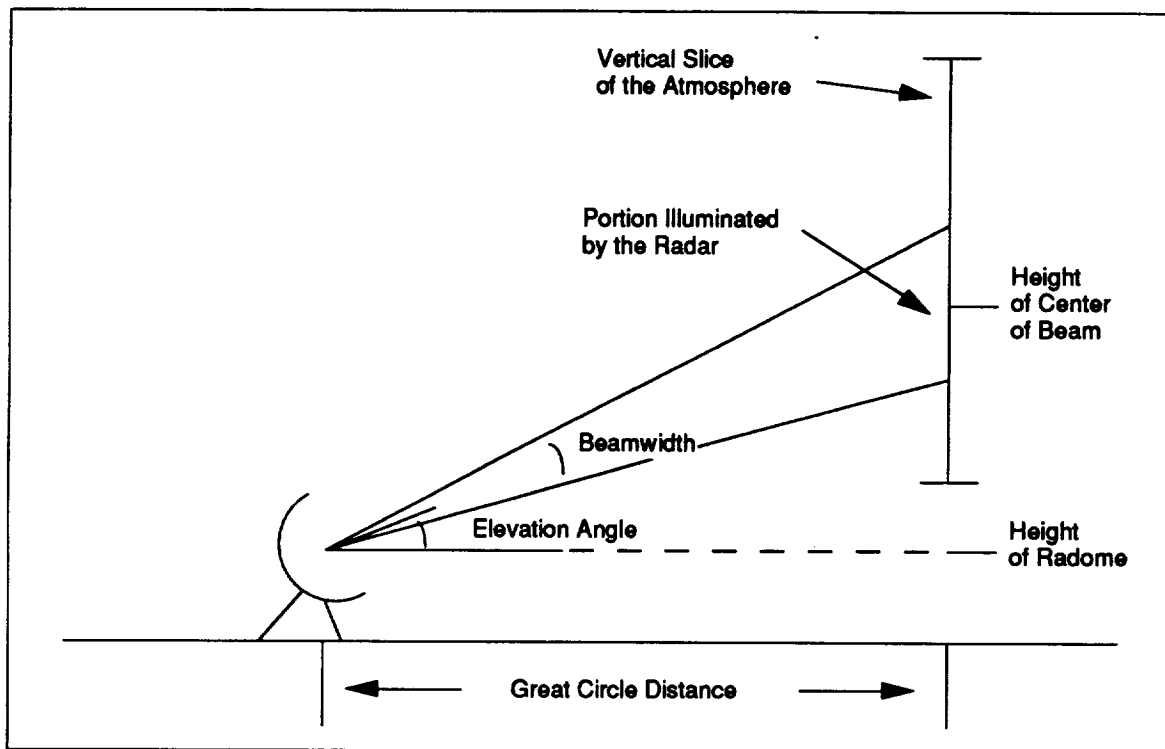


Figure 3.1. Conceptual illustration of the fraction of a vertical section of the atmosphere illuminated by one elevation scan of a radar.

It was mentioned in Section 2 that the RWO and SMG forecasters are generally concerned with critical weather phenomena within a 74 km radius cylinder from the launch / landing site. In this report, the 74 km radius cylinder depicted in the illustrations

is based on Launch Complex 39A as the center. Although using the SLF as the center would shift the cylinder about 7.5 km west of the cylinder depicted in the illustrations, it would not substantially alter the conclusions resulting from this analysis. Consequently, only the illustrations using Launch Complex 39A as the center of the cylinder are presented here.

3.1.1 Effective Earth Radius Model

For this analysis, the propagation of the radar beams was estimated using the Effective Earth Radius Model (Doviak and Zrnicek, 1993). This model estimates beam height, h , as a function of great circle distance, s , and the elevation angle of a ray leaving the radar, θ , as

$$h = a_e * \left[\frac{\cos(\theta)}{\cos\left(\theta + \frac{s}{a_e}\right)} - 1 \right]$$

In this model, a_e is the effective earth radius and, based upon research results, is

$$a_e = \frac{4a}{3}$$

where a is the earth's radius.

For weather radar applications, this model can be used for all elevation angles if h is restricted to the first 10-20 km of the atmosphere and if the index of refraction has a gradient of approximately $-1/(4a)$ in the first kilometer of the atmosphere (i.e., standard reference atmosphere). Severe departures from the standard atmosphere (e.g., large temperature inversions) produce anomalous index of refraction gradients and significant deviations in actual ray path from those predicted by the Effective Earth Radius Model.

3.2 WSR-74C / McGill Radar

The McGill radar under evaluation is a WSR-74C (5 cm radar) located at PAFB (Figure 3.5). It has a five minute update rate, a beam width of 1.1° , and uses 24 different scans from 0.6° to 35.97° elevation. The radar beam coverage of the McGill radar is illustrated in Figure 3.2. Although the lowest elevation scans provide good coverage, they are not efficient since they have considerable overlap. In addition, although the McGill radar uses 24 scans, the higher elevations scans are not contiguous resulting in gaps in radar coverage at higher altitudes near the radar.

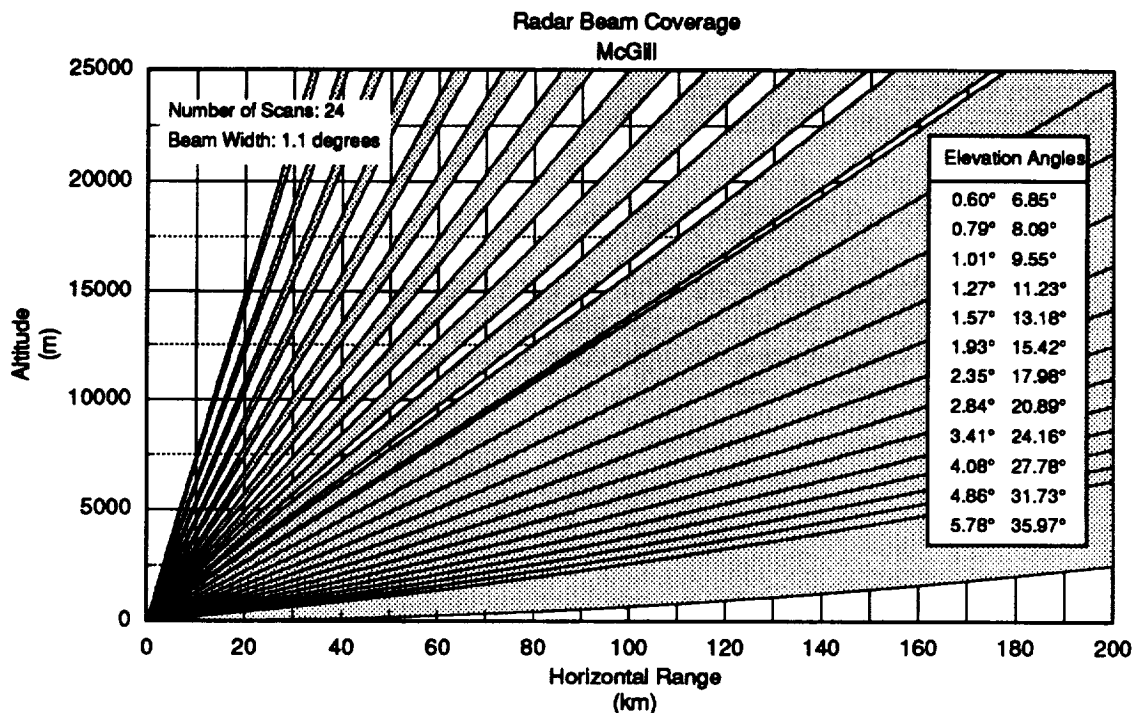


Figure 3.2. Radar beam coverage of the WSR-74C / McGill radar located at Patrick Air Force Base.

3.3 WSR-88D Radar at the Melbourne NWS Office

The WSR-88D radar under evaluation is the National Weather Service (NWS) radar located at the Melbourne NWS Office in Melbourne, Florida (Figure 3.6). The WSR-88D is a 10 cm radar with a 0.95° beam width and has two standard precipitation volume coverage patterns (VCP), the precipitation/severe weather scan (VCP 11) and the alternative precipitation scan (VCP 21). The Melbourne WSR-88D radar is approximately 17 km south-southwest of the PAFB WSR-74C / McGill radar.

The alternative precipitation scan strategy uses 9 scans from 0.48° to 19.51° elevation and has a six minute update rate. The lowest five elevation scans are contiguous; however, there are severe coverage gaps at most altitudes near the radar. VCP 21 is used primarily to reduce processing load on the Radar Products Generator (RPG) when the precipitation echoes of interest are far from the radar (e.g., of the order of 150 km). This VCP is not adequate for use in the evaluation of weather FR and LCC.

The precipitation/severe weather scan strategy uses 14 scans from 0.48° to 19.51° elevation and has a five minute update rate. The radar beam coverage of the VCP 11 is illustrated in Figure 3.3. The lowest seven elevation scans are contiguous, provide good radar coverage, and are more efficient (i.e., no overlap) than the corresponding McGill scans. The highest seven elevation scans are not contiguous resulting in gaps in radar coverage at higher altitudes near the radar.

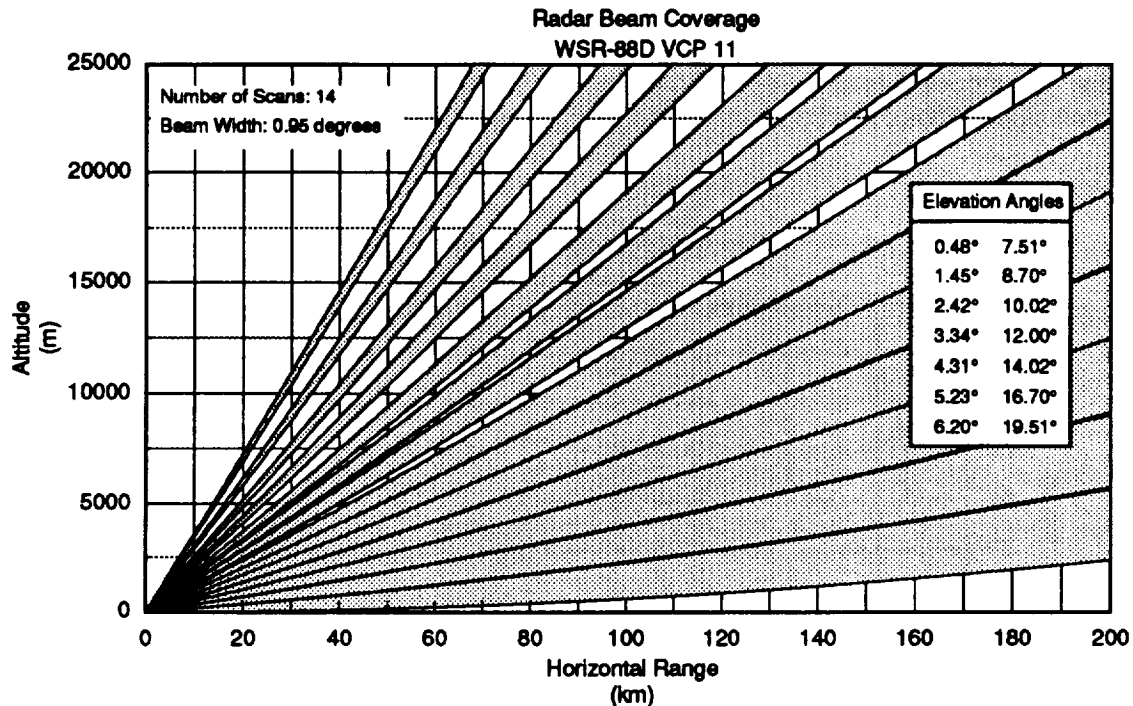


Figure 3.3. Radar beam coverage for Volume Coverage Pattern (VCP) 11 of the WSR-88D radar.

3.4 Comparison of Beam Coverage in the 1 to 4 km Layer

Figure 3.4 illustrates the percent of the atmosphere between 1 and 4 km above ground level sampled by the McGill radar and by the WSR-88D radar using VCP 11. The largest differences in percent of the atmosphere sampled occur within the a 10 km radius about the radars. This is a result of the higher elevation angles of the top scans within the McGill scan strategy as compared to the elevation angles of the top scans within VCP 11 of the WSR-88D. Within the band from 10 to 30 km of the radar, the McGill scan strategy samples approximately 5 to 10% more of the atmosphere than the VCP 11 scan strategy of the WSR-88D. Within the range from 35 to 150 km, there is little difference in the percent of the atmosphere sampled by the McGill radar and the WSR-88D using VCP 11. The radar coverage of both radars decreases outside of 120 km because the radius of curvature of the radar beam is less than the radius of curvature of the earth's surface. The analysis indicates that the beam coverage of the McGill radar exceeds 70% (good coverage) within the range of 15 to 170 km from the radar and the beam coverage of the WSR-88D using VCP 11 exceeds 70% within the range of 15 to 180 km from the radar.

Although the data in Figure 3.4 provide valuable information regarding the beam coverage of the scan strategies of the two radars, they do not provide a complete analysis of the beam coverage of the two radars relative to the use of the radars for weather FR and LCC evaluations since the two radars are not co-located and the distance from the radar to areas of concern are not included in the analysis. Consequently, the radar beam coverage of the 1 to 4 km layer of the atmosphere of the McGill radar located at PAFB and the WSR-88D using VCP 11 located at the NWS at Melbourne, Florida, relative to the east coast of Florida is presented in Figures 3.5 and 3.6. In both figures, the shaded region represents the cylinder of the atmosphere within 74 km (40 nautical miles) of

launch complex 39A which approximates the primary region of concern for use of the radars in weather FR and LCC evaluations. The data in the two figures indicate that the radar beam coverage exceeds 90% for both radars for the majority of the area within the region of concern. The beam coverage is poor only within 10 km of the radars.

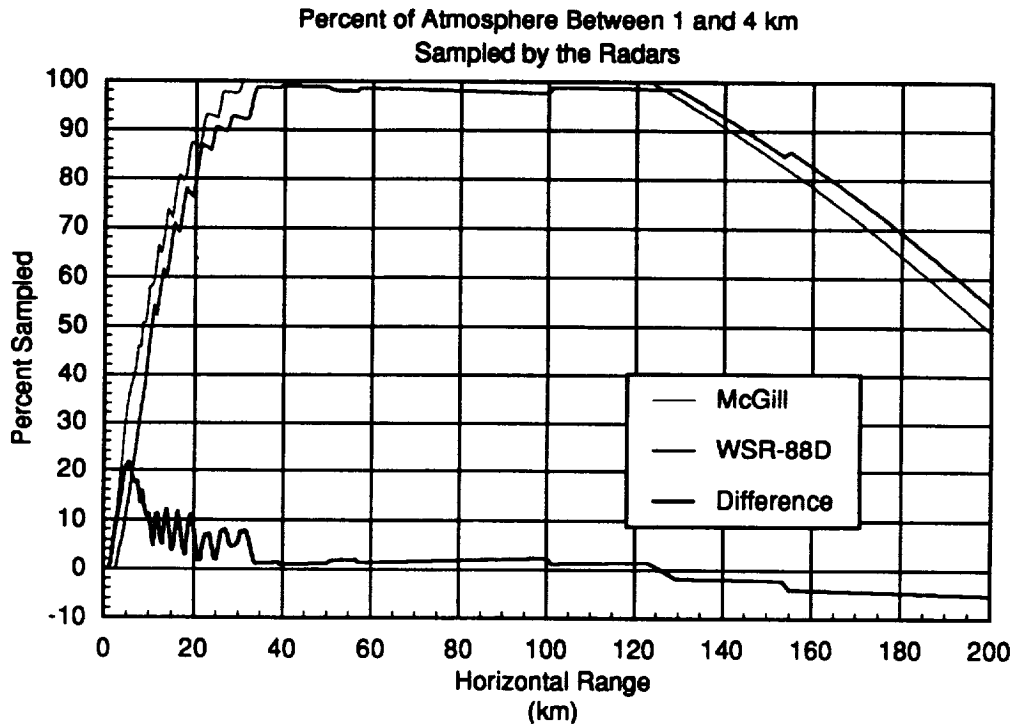


Figure 3.4. Percent of the atmosphere between 1 and 4 km above ground level sampled by the WSR-74C / McGill radar and the WSR-88D using VCP 11. The difference in percent of the atmosphere sampled is defined as the percent of the atmosphere sampled by the WSR-74C / McGill less the percent of the atmosphere sampled by the WSR-88D.

The difference in percent of the atmosphere sampled by the WSR-74C / McGill radar located at PAFB and the WSR-88D located at the NWS Office in Melbourne relative to the east coast of Florida is illustrated in Figure 3.7. The data indicate that the difference in beam coverage in the 1 and 4 km layer between the two radars is less than 10% for most of the area of concern. However, because of the different scan strategies employed by the two radars and the different locations of the two radars, there are limited regions of significant differences in radar beam coverage between the two radars within the area of concern. For example, the McGill radar provides better radar beam coverage in the extreme southern region of the area of concern. Conversely, the WSR-88D provides slightly better radar beam coverage over the region extending from the McGill radar site to Cape Canaveral.

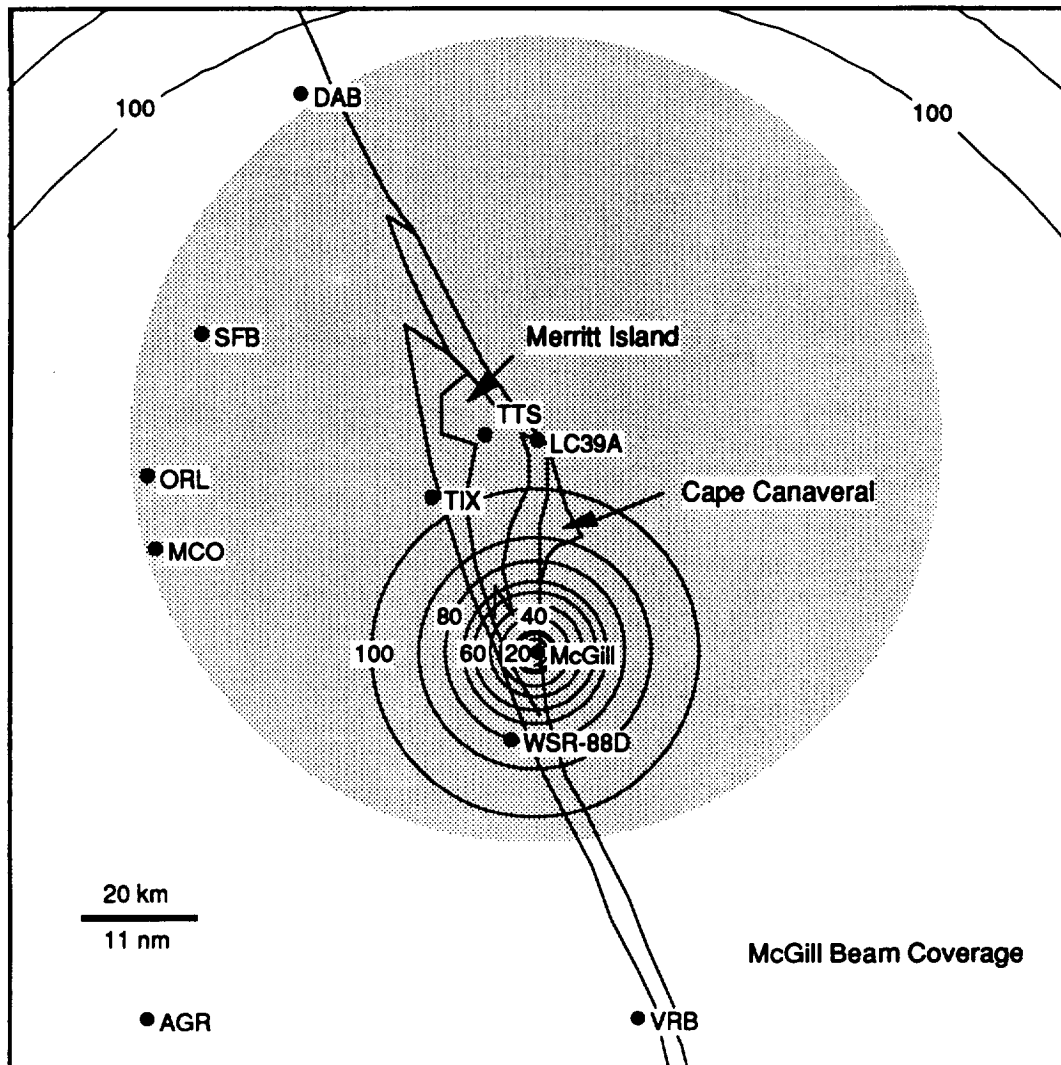


Figure 3.5. Isolines represent percent of the atmosphere between 1 and 4 km above ground level sampled by the WSR-74C / McGill radar located at PAFB. Shaded region represents the cylinder of the atmosphere within 74 km (40 nautical miles) of launch complex 39A. Acronyms and abbreviations used are: TTS = Shuttle Landing Facility, TIX = Tico Executive, DAB = Daytona Beach, SFB = Sanford, ORL = Orlando Executive, MCO = Orlando International, AGR = Avon Park, VRB = Vero Beach, LC39A = Launch Complex 39A.

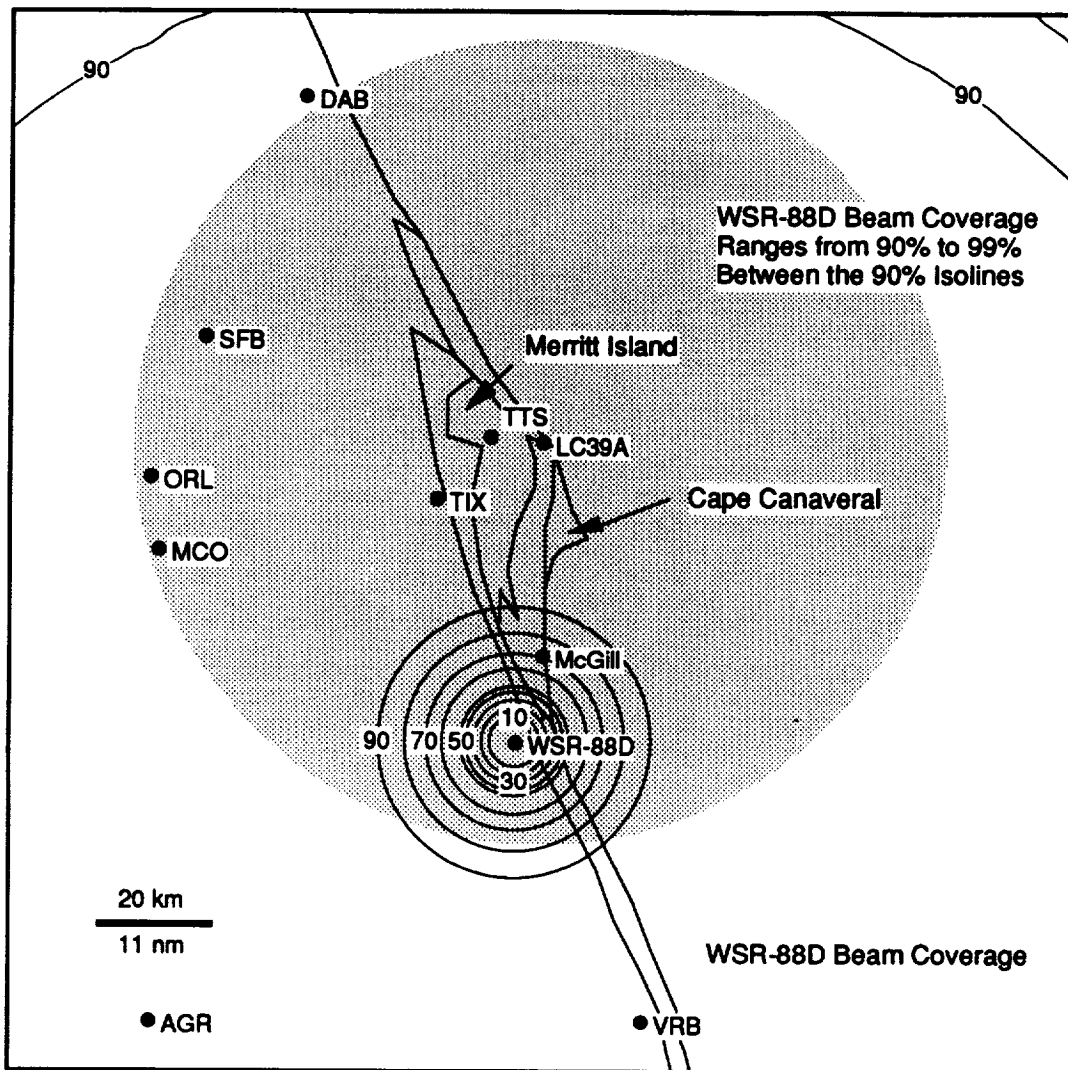


Figure 3.6. Isolines represent percent of the atmosphere between 1 and 4 km above ground level sampled by the WSR-88D located at the NWS Office in Melbourne, FL, using VCP 11. Shaded region represents the cylinder of the atmosphere within 74 km (40 nautical miles) of launch complex 39A. Acronyms and abbreviations used are as in Figure 3.5.

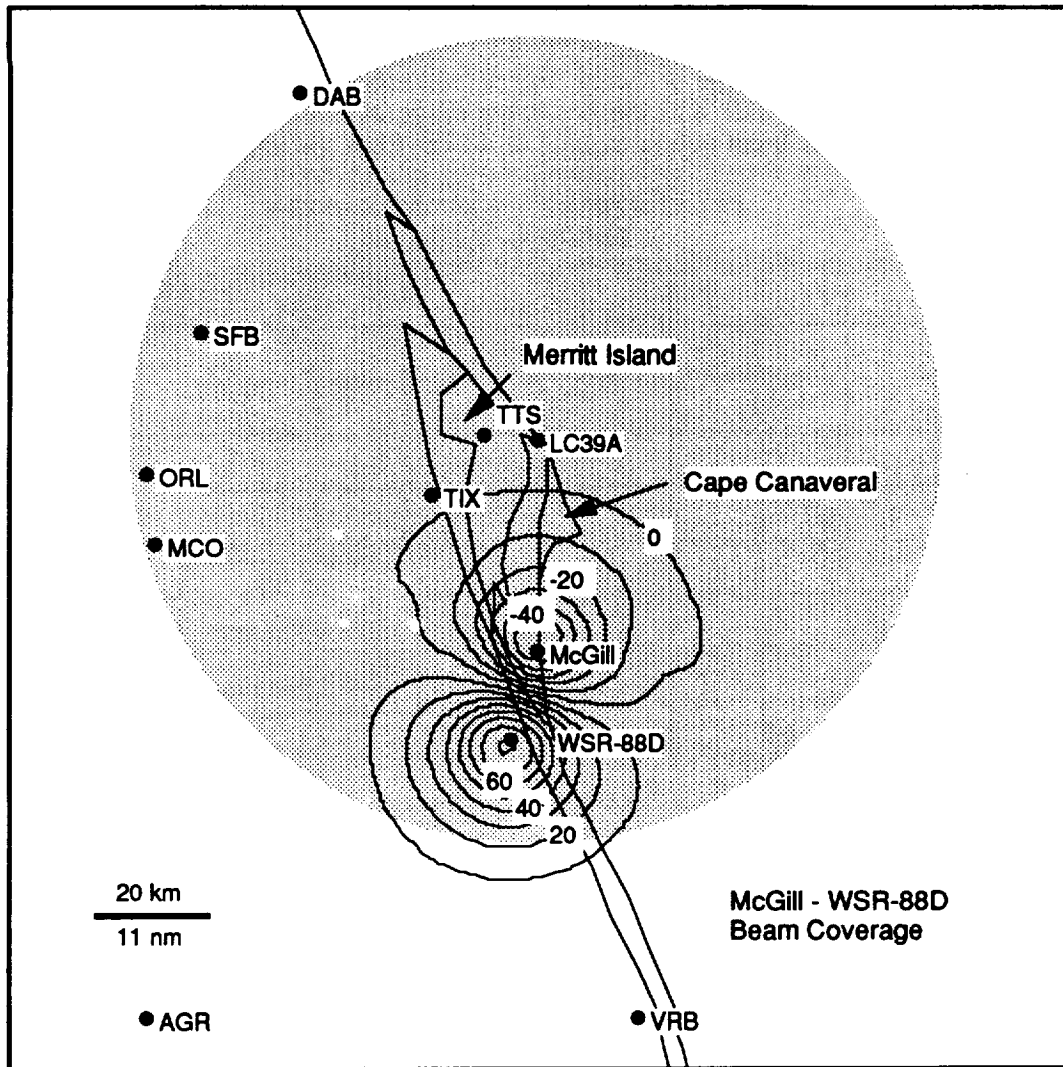


Figure 3.7. Isolines represent the difference in percent of the atmosphere between 1 and 4 km above ground level sampled by the WSR-74C / McGill radar located at PAFB and the WSR-88D located at the NWS Office in Melbourne, FL, using VCP 11. The difference in percent of the atmosphere sampled is defined as the percent of the atmosphere sampled by the WSR-74C / McGill less the percent of the atmosphere sampled by the WSR-88D. Thus, positive values indicate superior coverage by the McGill radar. Shaded region represents the cylinder of the atmosphere within 74 km (40 nautical miles) of launch complex 39A. Acronyms and abbreviations used are as in Figure 3.5.

3.5 Comparison of Beam Coverage in the 4 to 8 km Layer

Figure 3.8 illustrates the percent of the atmosphere between 4 and 8 km above ground level sampled by the McGill radar and by the WSR-88D radar using VCP 11. The largest differences in percent of the atmosphere sampled occur within 20 km of the radar. This is a result of the higher elevation angles of the top scans within the McGill scan strategy as compared to the elevation angles of the top scans within VCP 11 of the WSR-88D. Within the band from 20 to 65 km of the radar, the McGill scan strategy samples approximately 10% more of the atmosphere than the VCP 11 scan strategy of the

WSR-88D. Outside of 65 km, there is little difference in the percent of the atmosphere sampled by the McGill radar and the WSR-88D using VCP 11. The data in figure 3.8 indicate that the beam coverage of the McGill radar exceeds 70% in the 4 to 8 km region outside of 35 km from the radar and the beam coverage of the WSR-88D using VCP 11 exceeds 70% in the 4 to 8 km region outside of 40 km from the radar.

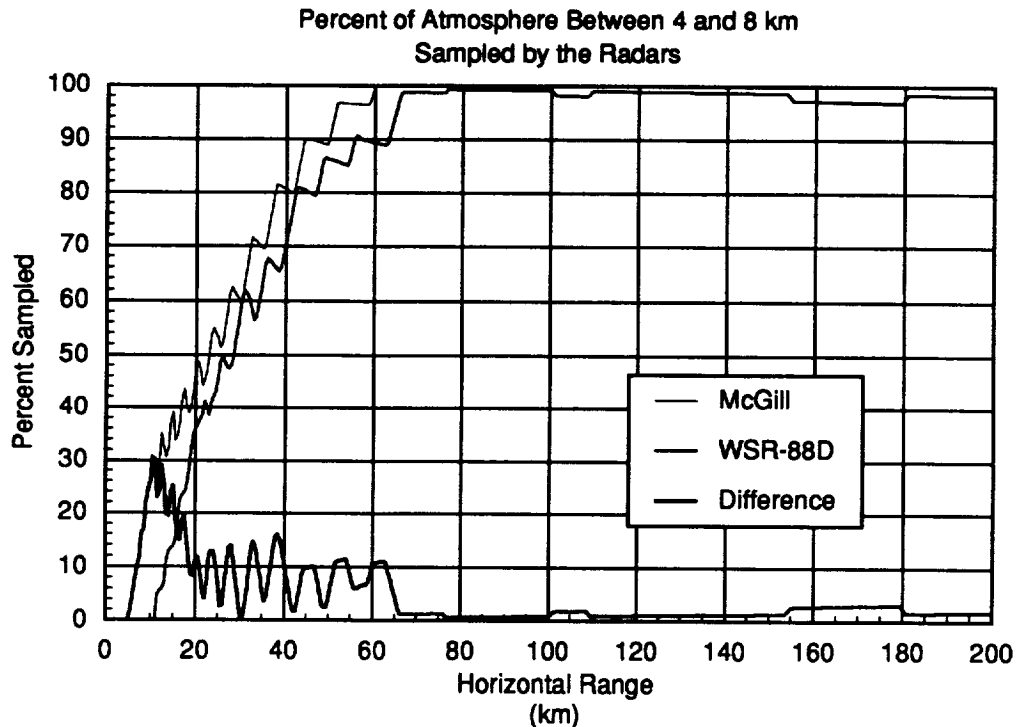


Figure 3.8. Percent of the atmosphere between 4 and 8 km above ground level sampled by the WSR-74C / McGill radar and the WSR-88D using VCP 11. The difference in percent of the atmosphere sampled is defined as the percent of the atmosphere sampled by the WSR-74C / McGill less the percent of the atmosphere sampled by the WSR-88D.

The radar beam coverage of the 4 to 8 km layer of the atmosphere of the McGill radar located at PAFB and the WSR-88D using VCP 11 located at the NWS at Melbourne, Florida, relative to the east coast of Florida is presented in Figures 3.9 and 3.10. The data in the two figures indicate that the beam coverage exceeds 70% for both radars for the majority of the area within the region of concern and exceeds 90% for both radars for almost all of the northern half of the area of concern. However, the beam coverage of both radars is less than 50% for a limited area within the southern half of the region of concern.

The difference in percent of the atmosphere sampled by the WSR-74C /McGill radar located at PAFB and the WSR-88D located at the NWS Office in Melbourne relative to the east coast of Florida is illustrated in Figure 3.11. The data indicate that the difference in beam coverage in the 4 and 8 km layer between the two radars is less than 10% for most of the area of concern. However, there are limited regions of significant differences in radar beam coverage between the two radars within the area of concern. Similar to the differences in beam coverage in the 1 to 4 km layer, the McGill radar provides better radar beam coverage in the extreme southern region of the area of concern. Conversely, the WSR-88D provides slightly better radar beam coverage over the region extending from the McGill radar site to Cape Canaveral.

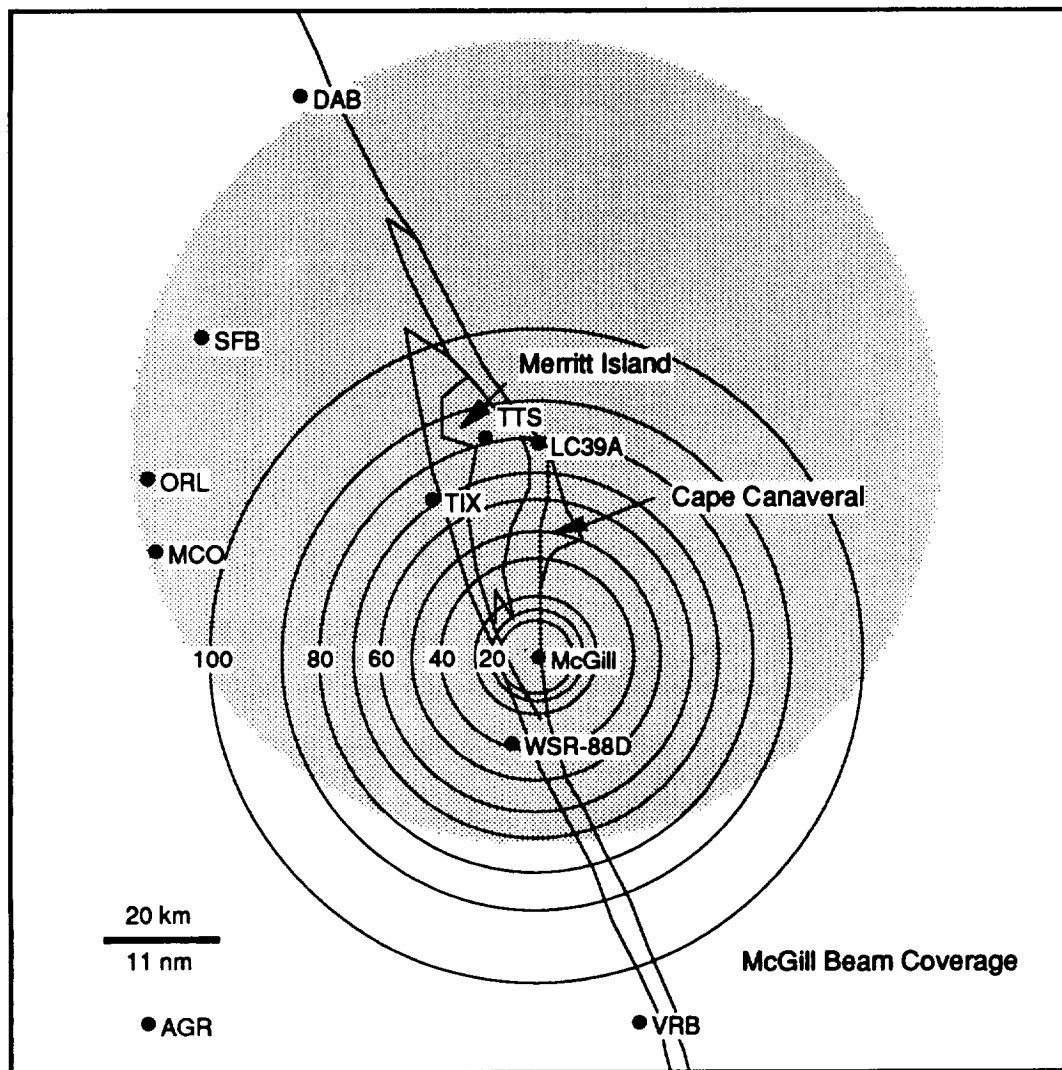


Figure 3.9. Isolines represent percent of the atmosphere between 4 and 8 km above ground level sampled by the WSR-74C / McGill radar located at PAFB. Shaded region represents the cylinder of the atmosphere within 74 km (40 nautical miles) of launch complex 39A. Acronyms and abbreviations used are as in Figure 3.5.

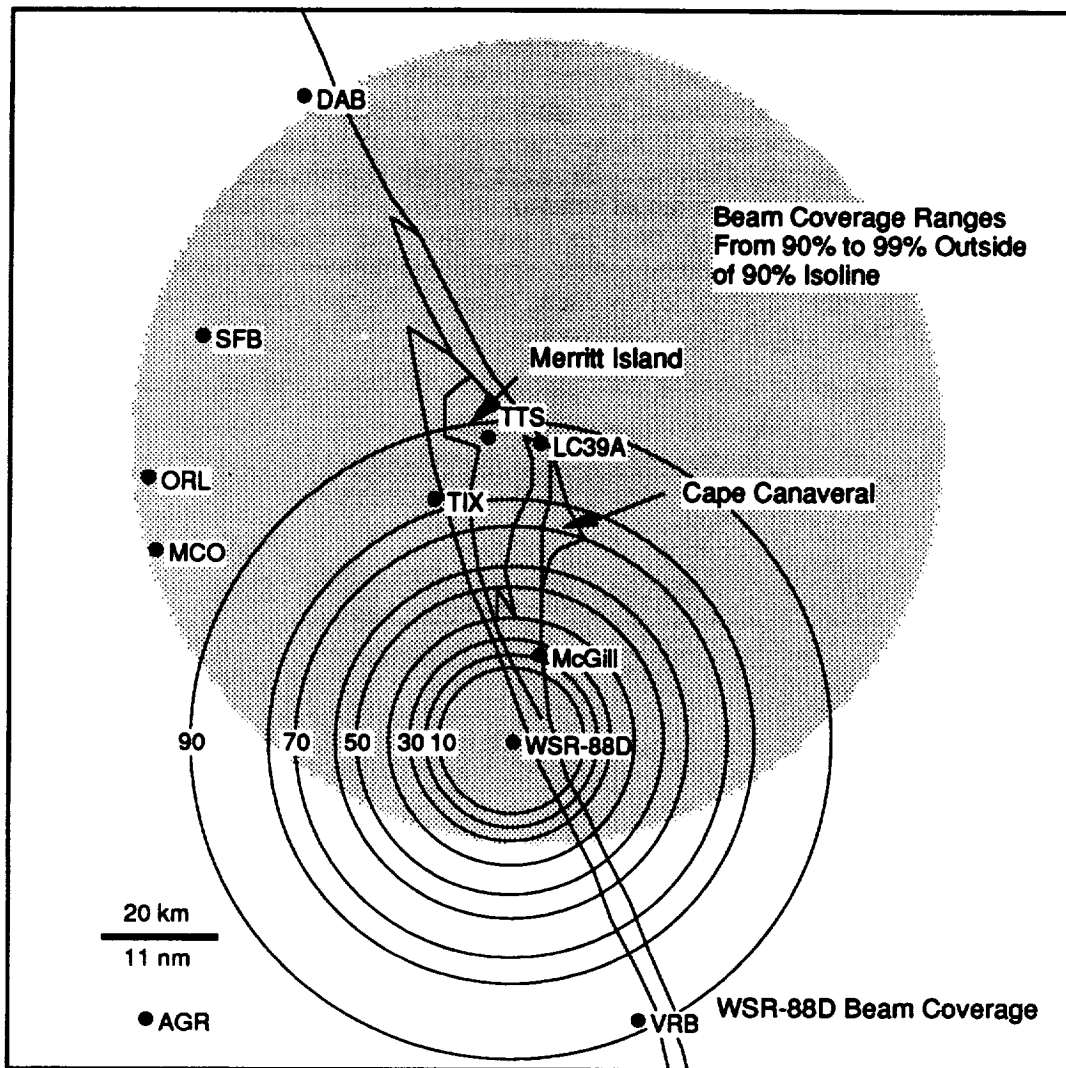


Figure 3.10. Isolines represent percent of the atmosphere between 4 and 8 km above ground level sampled by the WSR-88D located at the NWS Office in Melbourne, FL, using VCP 11. Shaded region represents the cylinder of the atmosphere within 74 km (40 nautical miles) of launch complex 39A. Acronyms and abbreviations used are as in Figure 3.5.

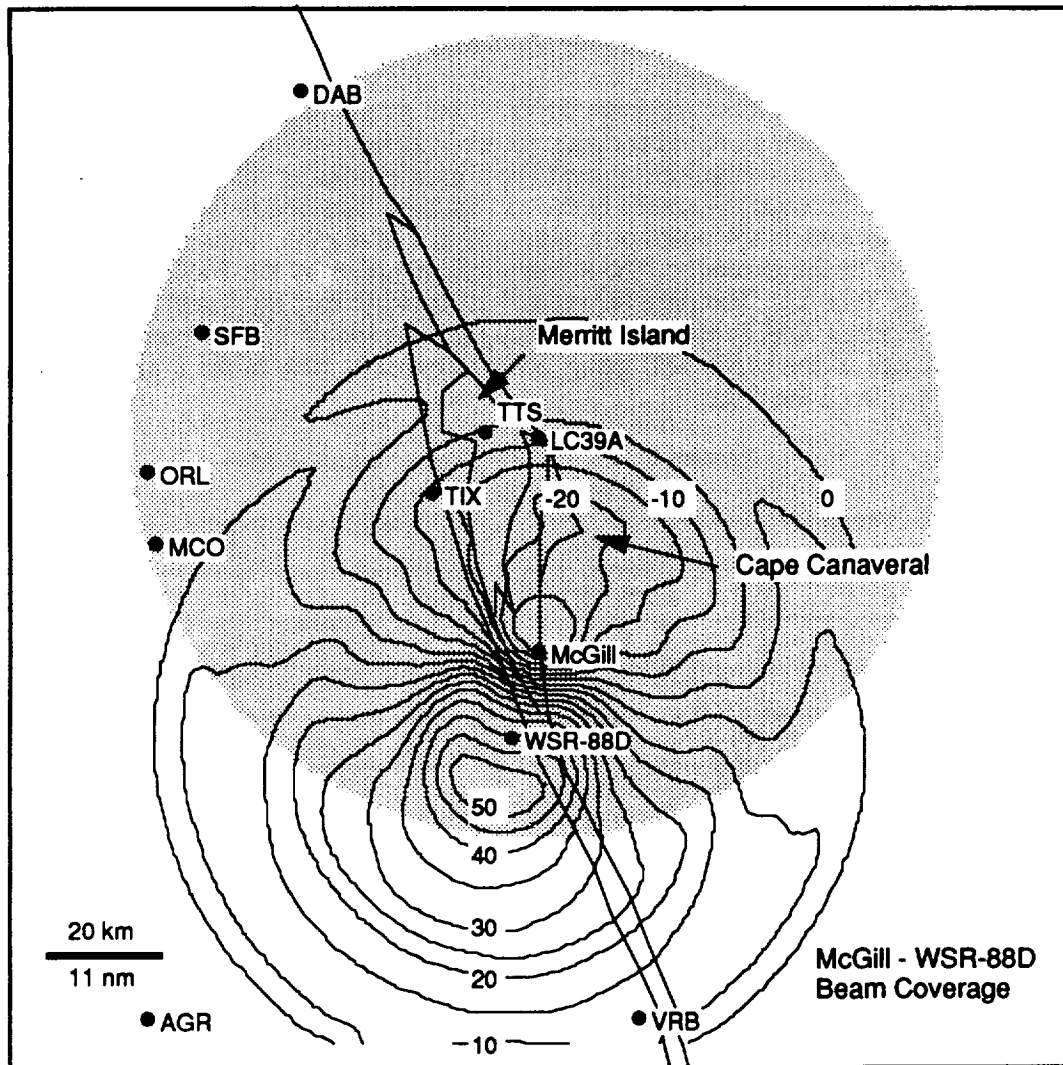


Figure 3.11. Isolines represent the difference in percent of the atmosphere between 4 and 8 km above ground level sampled by the WSR-74C / McGill radar located at PAFB and the WSR-88D located at the NWS Office in Melbourne, FL, using VCP 11. The difference in percent of the atmosphere sampled is defined as the percent of the atmosphere sampled by the WSR-74C / McGill less the percent of the atmosphere sampled by the WSR-88D. Thus, positive values indicate superior coverage by the McGill radar. Shaded region represents the cylinder of the atmosphere within 74 km (40 nautical miles) of launch complex 39A. Acronyms and abbreviations used are as in Figure 3.5.

3.6 Comparison of Beam Coverage in the 8 to 12 km Layer

Figure 3.12 illustrates the percent of the atmosphere between 8 and 12 km above ground level sampled by the McGill radar and by the WSR-88D radar using VCP 11. Although the beam coverage for both radars increases with increasing distance from the radar, there are substantial small-scale fluctuations in the beam coverage embedded within the large-scale pattern. The small-scale fluctuations result from the significant gaps in the beam coverage within the higher elevation scans for both radars (Figures 3.2 and 3.3).

The largest differences in percent of the atmosphere sampled occur within 25 km of the radar. This is a result of the higher elevation angles of the top scans within the McGill scan strategy as compared to the elevation angles of the top scans within VCP 11 of the WSR-88D. Within the band from 25 to 95 km of the radar, the mean difference in percent of the atmosphere sampled is approximately 10% (McGill beam coverage greater than WSR-88D beam coverage) but varies from approximately -8% to 25%. The large variability in the difference in percent of the atmosphere sampled is due to the substantial small-scale fluctuations in the beam coverage within this region. Outside of 95 km, there is little difference in the percent of the atmosphere sampled by the McGill radar and the WSR-88D using VCP 11. The data in figure 3.12 indicate that the beam coverage of the McGill radar exceeds 70% in the 8 to 12 km region outside of 55 km from the radar and the beam coverage of the WSR-88D using VCP 11 exceeds 70% in the 8 to 12 km region outside of 60 km from the radar.

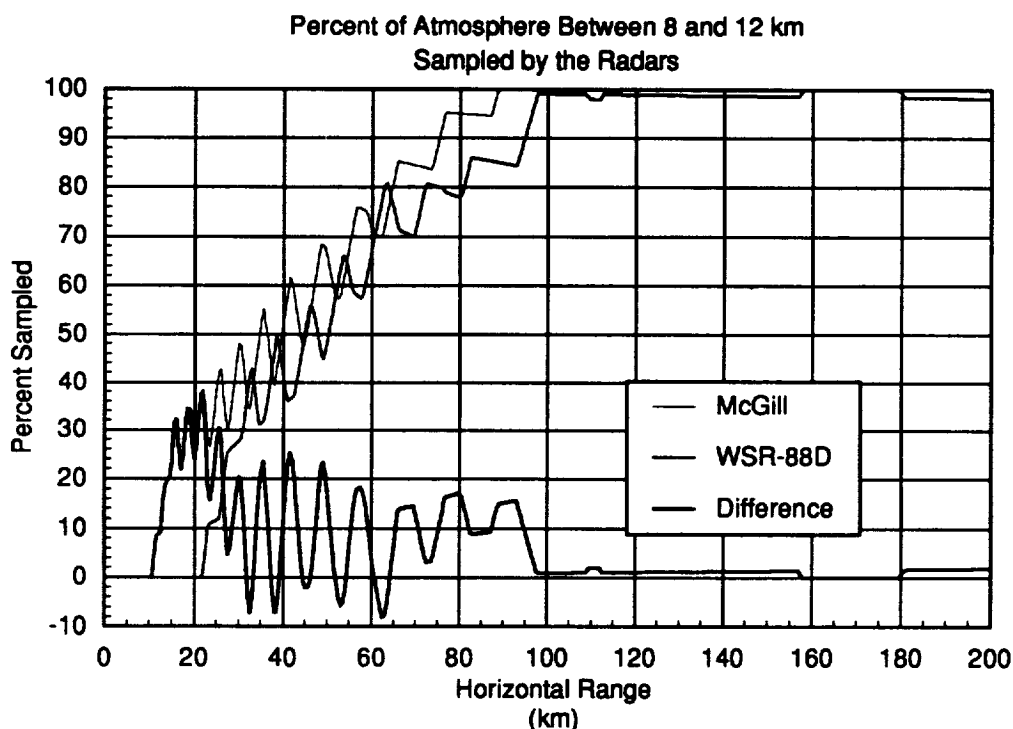


Figure 3.12. Percent of the atmosphere between 8 and 12 km above ground level sampled by the WSR-74C / McGill radar and the WSR-88D using VCP 11. The difference in percent of the atmosphere sampled is defined as the percent of the atmosphere sampled by the WSR-74C / McGill less the percent of the atmosphere sampled by the WSR-88D.

The radar beam coverage of the 8 to 12 km layer of the atmosphere of the McGill radar located at PAFB and the WSR-88D using VCP 11 located at the NWS at Melbourne, Florida, relative to the east coast of Florida is presented in Figures 3.13 and 3.14. The data in the two figures indicate that the radar beam coverage exceeds 70% for both radars for most all of the area within the northern hemisphere of the region of concern. However, the radar beam coverage of both radars is less than 50% for a significant portion of the area within the southern hemisphere of the region of concern and is less than 70% for most all of the KSC / Cape Canaveral Air Station (CCAS) region.

The beam coverage in the 8 to 12 km region for both radars is poorer over most of the region of concern than the corresponding beam coverage in the 1 to 4 km region and the 4 to 8 km region. In the case of the McGill radar, the poorer beam coverage is due primarily to the significant gaps in the beam coverage within the higher elevation scans (Figure 3.2). In the case of the WSR-88D, the poorer beam coverage is due to both the significant gaps in the beam coverage within the higher elevation scans and the limited highest elevation scan (Figure 3.3).

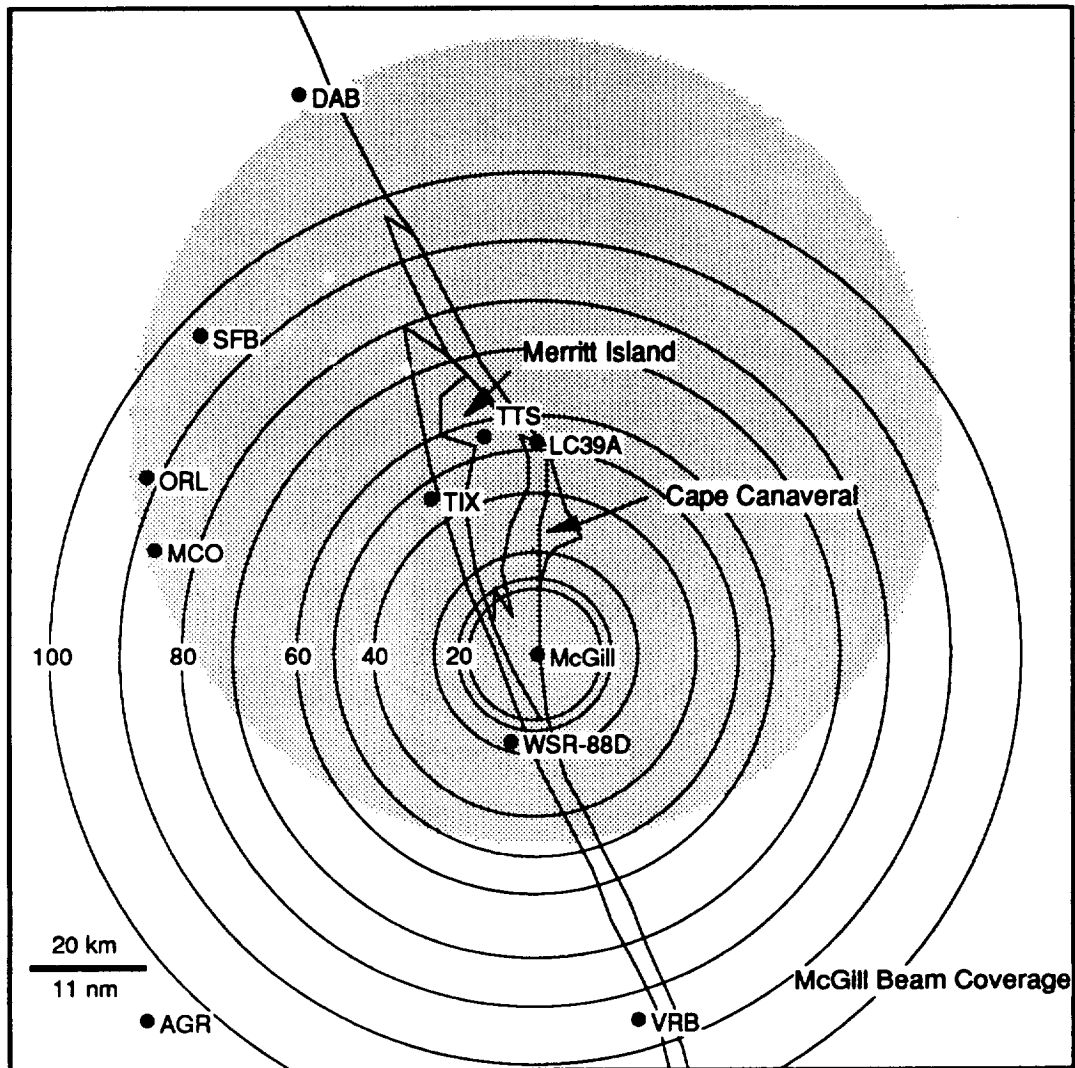


Figure 3.13. Isolines represent percent of the atmosphere between 8 and 12 km above ground level sampled by the WSR-74C / McGill radar located at PAFB. Shaded region represents the cylinder of the atmosphere within 74 km (40 nautical miles) of launch complex 39A. Acronyms and abbreviations used are as in Figure 3.5.

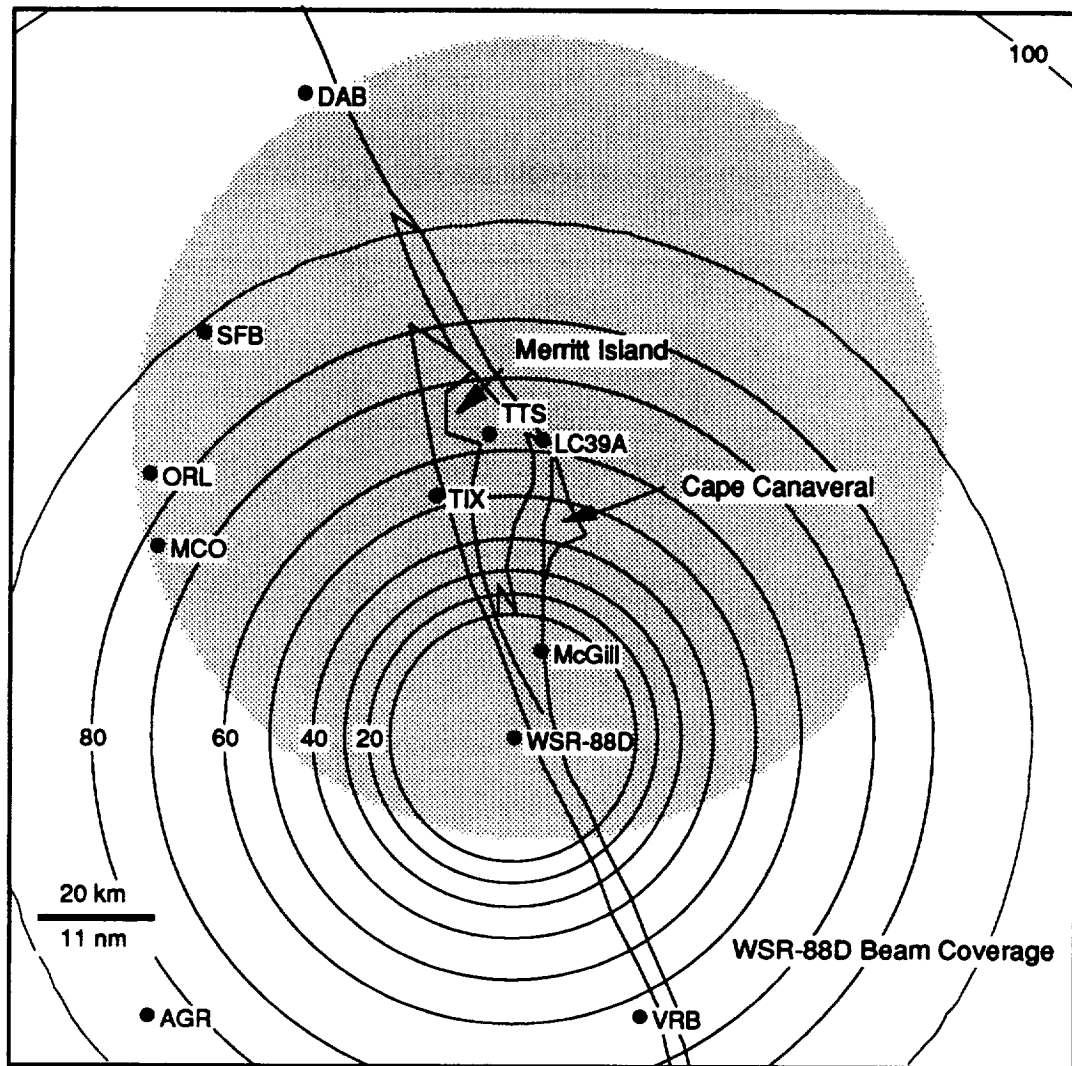


Figure 3.14. Isolines represent percent of the atmosphere between 8 and 12 km above ground level sampled by the WSR-88D located at the NWS Office in Melbourne, FL, using VCP 11. Shaded region represents the cylinder of the atmosphere within 74 km (40 nautical miles) of launch complex 39A. Acronyms and abbreviations used are as in Figure 3.5

The difference in percent of the atmosphere sampled by the WSR-74C /McGill radar located at PAFB and the WSR-88D located at the NWS Office in Melbourne relative to the east coast of Florida is illustrated in Figure 3.15. Because of the significant small-scale fluctuations in beam coverage (Figure 3.12), the difference pattern is rather complex. But most importantly, the data indicate that the difference in beam coverage in the 8 and 12 km layer between the two radars is less than 10% for more than half of the area of concern. The largest differences in percent of the atmosphere sampled (40%) occur to the south-southwest of the WSR-88D radar. In this region, the McGill radar has a distinct beam coverage advantage over the WSR-88D. Conversely, the WSR-88D has slightly better radar beam coverage over most of the KSC / CCAS region. The advantages inherent in the scan strategy of the McGill radar are offset by the location of the WSR-88D relative to the McGill radar and KSC / CCAS resulting in slightly better radar beam coverage by the WSR-88D over most of the KSC / CCAS region.

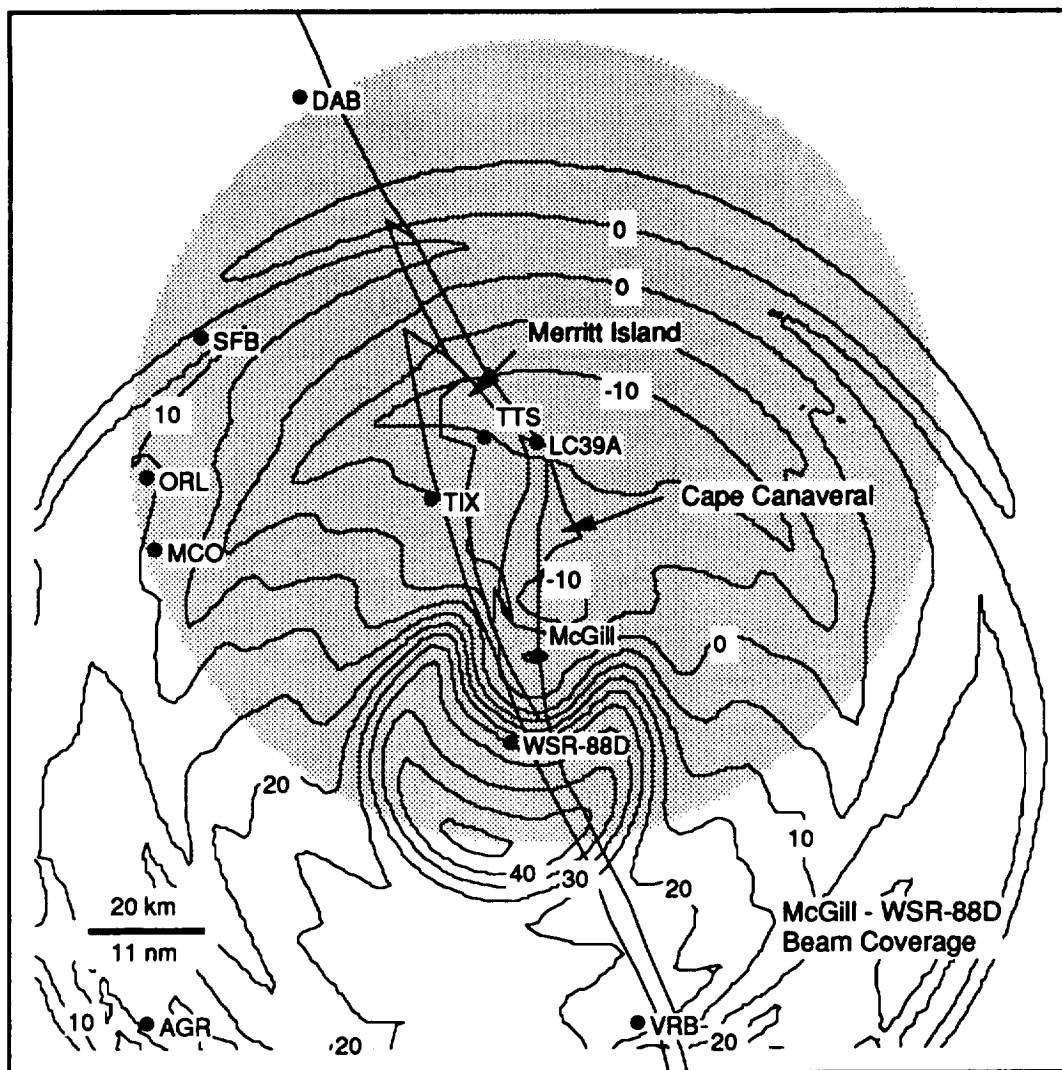


Figure 3.15. Isolines represent the difference in percent of the atmosphere between 8 and 12 km above ground level sampled by the WSR-74C / McGill radar located at PAFB and the WSR-88D located at the NWS Office in Melbourne, FL, using VCP 11. The difference in percent of the atmosphere sampled is defined as the percent of the atmosphere sampled by the WSR-74C / McGill less the percent of the atmosphere sampled by the WSR-88D. Thus, positive values indicate superior coverage by the McGill radar. Shaded region represents the cylinder of the atmosphere within 74 km (40 nautical miles) of launch complex 39A. Acronyms and abbreviations used are as in Figure 3.5.

3.7 Comparison of Beam Coverage in the 1 to 12 km Layer

Figure 3.16 illustrates the percent of the atmosphere between 1 and 12 km above ground level sampled by the McGill radar and by the WSR-88D radar using VCP 11. The largest differences in percent of the atmosphere sampled occur within 25 km of the radar. This is a result of the higher elevation angles of the top scans within the McGill scan strategy as compared to the elevation angles of the top scans within VCP 11 of the WSR-88D. Within the band from 25 to 95 km of the radar, the McGill scan strategy samples approximately 5 to 10% more of the atmosphere than the VCP 11 scan strategy

of the WSR-88D. Outside of 100 km, there is little difference in the percent of the atmosphere sampled by the McGill radar and the WSR-88D using VCP 11. The data indicate that the beam coverage of the McGill radar exceeds 70% in the 1 to 12 km region outside of 35 km from the radar and the beam coverage of the WSR-88D using VCP 11 exceeds 70% in the 1 to 12 km region outside of 45 km from the radar. The radar coverage of both radars decreases outside of 120 km because the radius of curvature of the radar beam is less than the radius of curvature of the earth's surface.

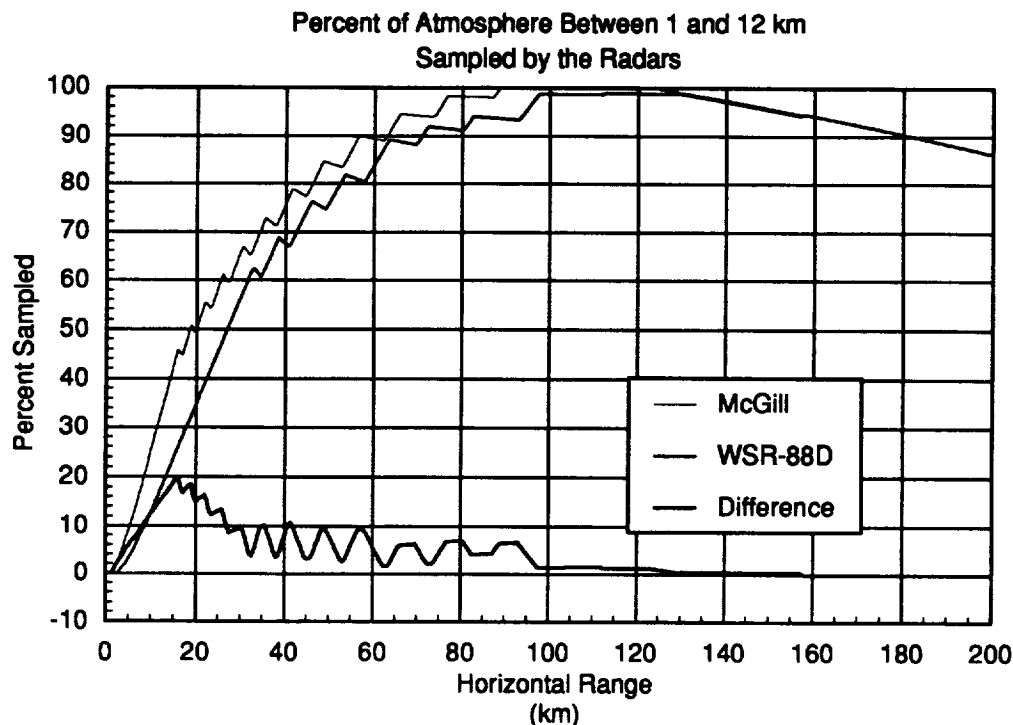


Figure 3.16. Percent of the atmosphere between 1 and 12 km above ground level sampled by the WSR-74C / McGill radar and the WSR-88D using VCP 11. The difference in percent of the atmosphere sampled is defined as the percent of the atmosphere sampled by the WSR-74C / McGill less the percent of the atmosphere sampled by the WSR-88D.

The radar beam coverage of the 1 to 12 km layer of the atmosphere of the McGill radar located at PAFB and the WSR-88D using VCP 11 located at the NWS at Melbourne, Florida, relative to the east coast of Florida is presented in Figures 3.17 and 3.18. The data in the two figures indicate that the radar beam coverage exceeds 70% for both radars for the majority of the area within the region of concern. However, the radar beam coverage of the McGill radar is less than 50% for a limited area near the radar including the southern tip of Cape Canaveral. Similarly, the radar beam coverage of the WSR-88D radar is less than 50% for a limited area near the radar.

The difference in percent of the atmosphere between 1 and 12 km sampled by the WSR-74C / McGill radar located at PAFB and the WSR-88D located at the NWS Office in Melbourne relative to the east coast of Florida is illustrated in Figure 3.19. The data indicate that the difference in beam coverage in the 1 and 12 km layer between the two radars is less than 10% for more than half of the area of concern. The largest differences in percent of the atmosphere sampled (45%) occur to the south-southwest of the WSR-88D radar. In this region, the McGill radar has a distinct beam coverage advantage

over the WSR-88D. Conversely, the WSR-88D has slightly better radar beam coverage (5 to 15% greater) than the McGill radar over most of the KSC / CCAS region.

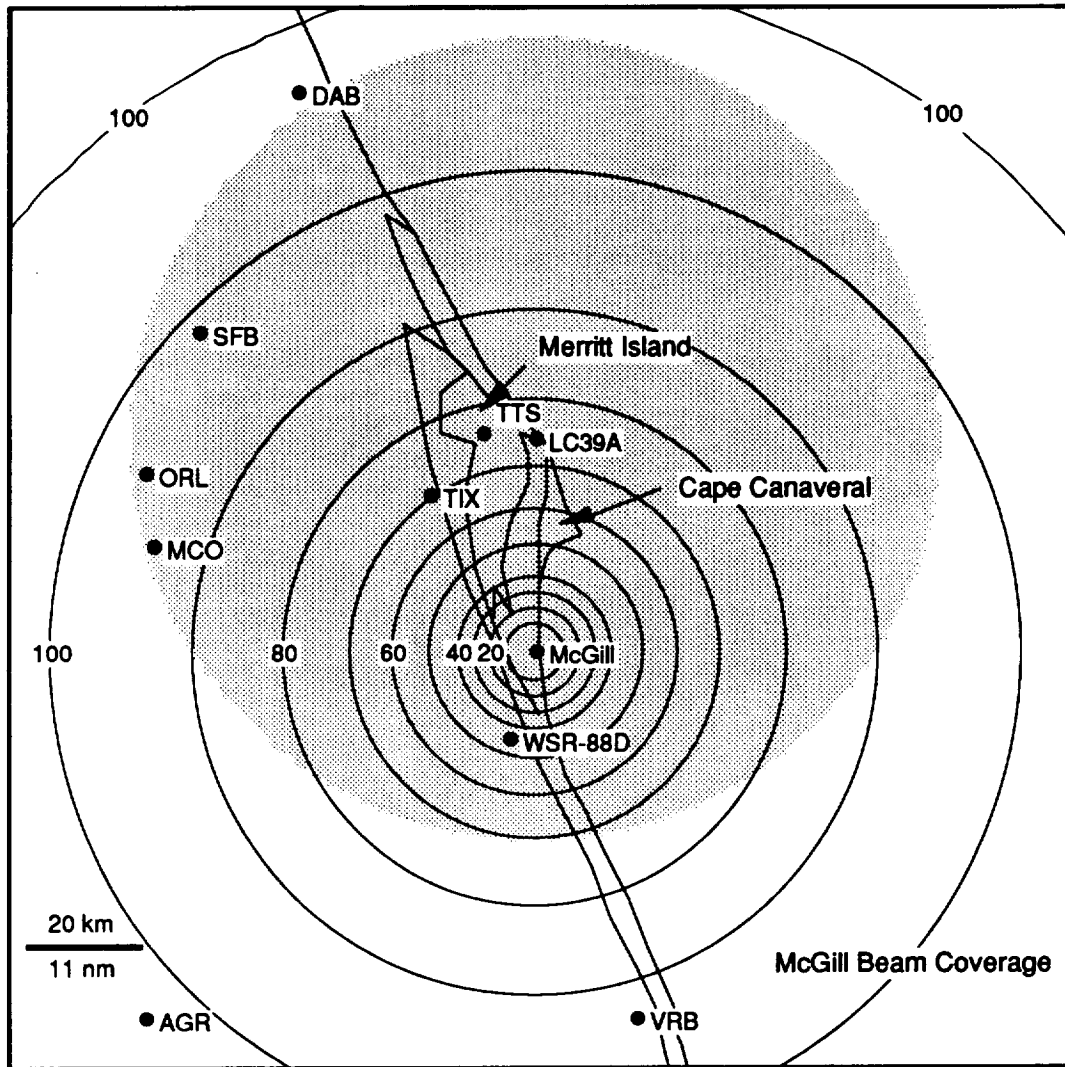


Figure 3.17. Isolines represent percent of the atmosphere between 1 and 12 km above ground level sampled by the WSR-74C / McGill radar located at PAFB. Shaded region represents the cylinder of the atmosphere within 74 km (40 nautical miles) of launch complex 39A. Acronyms and abbreviations used are as in Figure 3.5.

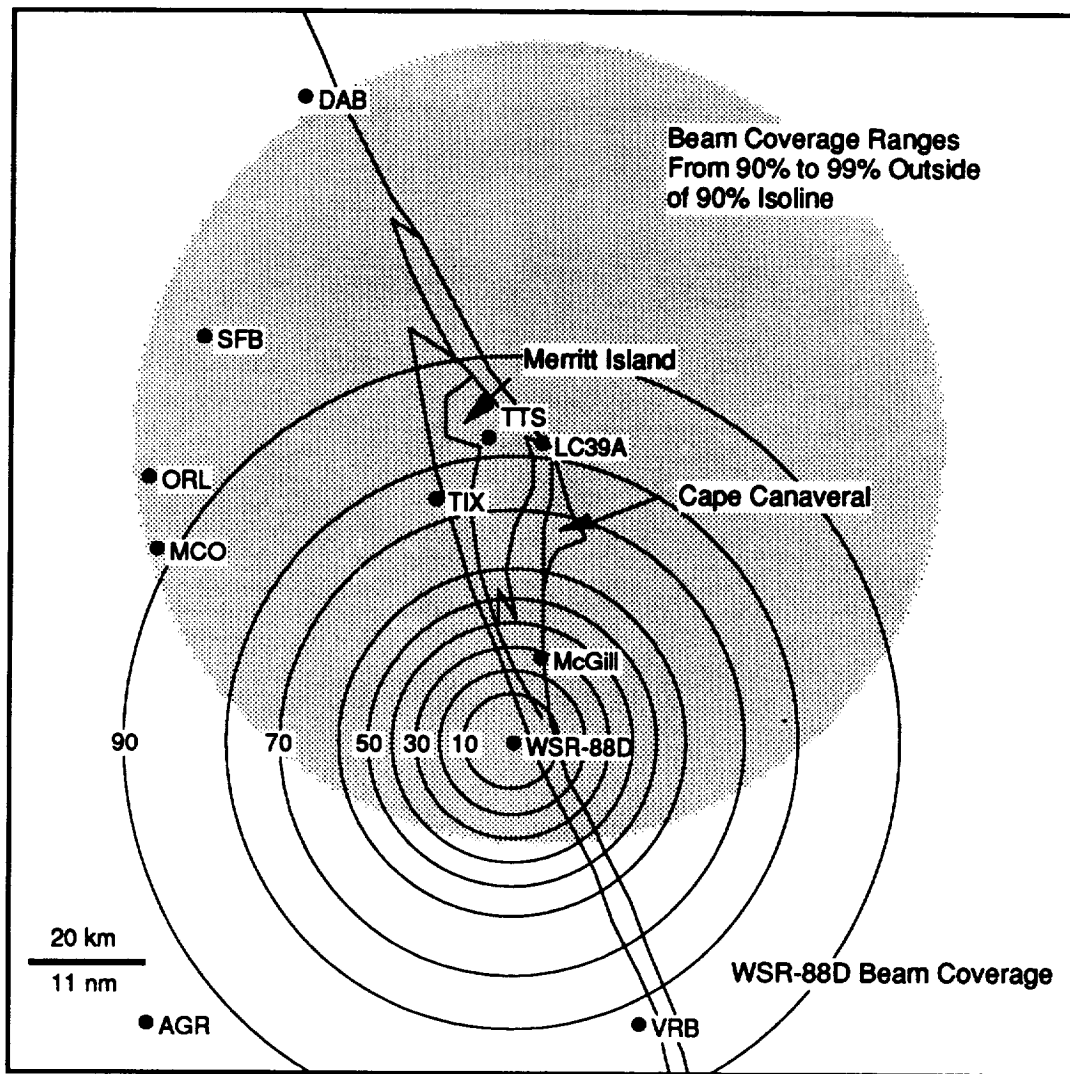


Figure 3.18. Isolines represent percent of the atmosphere between 1 and 12 km above ground level sampled by the WSR-88D located at the NWS Office in Melbourne, FL, using VCP 11. Shaded region represents the cylinder of the atmosphere within 74 km (40 nautical miles) of launch complex 39A. Acronyms and abbreviations used are as in Figure 3.5.

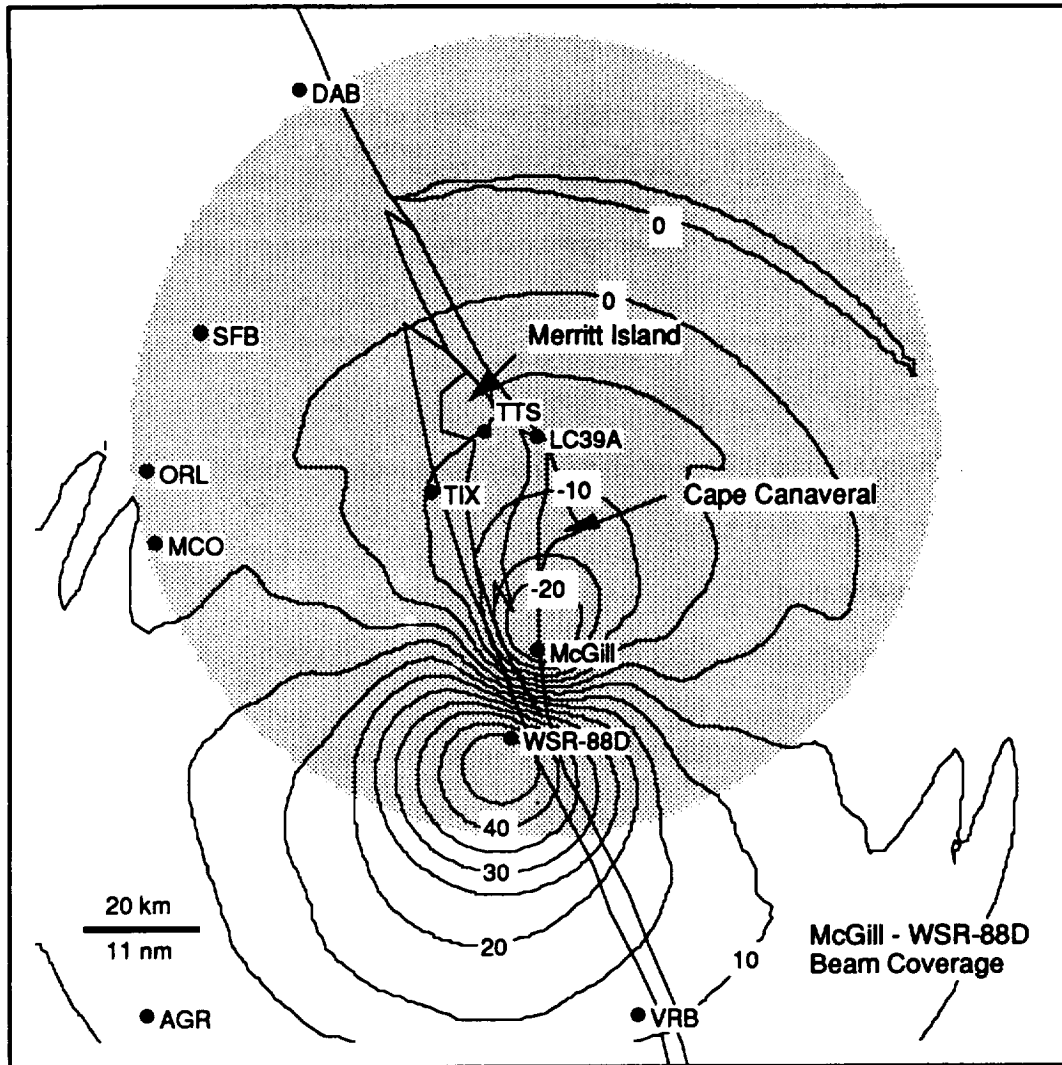


Figure 3.19. Isolines represent the difference in percent of the atmosphere between 1 and 12 km above ground level sampled by the WSR-74C / McGill radar located at PAFB and the WSR-88D located at the NWS Office in Melbourne, FL, using VCP 11. The difference in percent of the atmosphere sampled is defined as the percent of the atmosphere sampled by the WSR-74C / McGill less the percent of the atmosphere sampled by the WSR-88D. Thus, positive values indicate superior coverage by the McGill radar. Shaded region represents the cylinder of the atmosphere within 74 km (40 nautical miles) of launch complex 39A. Acronyms and abbreviations used are as in Figure 3.5.

4.0 Issues and Concerns

In addition to the scan strategy comparison, there are other characteristics of the two radars that should be considered in the process of determining if the WSR-88D located at the Melbourne NWS Office could be used to perform the essential functions now performed by the PAFB WSR-74C / McGill radar for evaluating Shuttle weather FR and LCC. A partial list of additional radar system characteristics which deserve consideration include:

- Radar digitizers
- Radar side lobe patterns
- Ability and cost of customizing radar system capabilities (i.e., VSR0C)
- Ease of use of system
- Life cycle costs
- Other system limitations (e.g. load shedding by the WSR-88D).

The one item on the above list which requires some explanation is "load shedding by the WSR-88D." Under certain conditions (e.g., an update cycle characterized by numerous precipitation echoes and a number of one-time products requests from associated PUPs and / or non-associated PUPs), the processing load on the RPG may become too great for the RPG to produce all of the requested products within the update cycle. In this event, the RPG will not produce or will "shed" a limited number of the products such that all remaining products can be produced and distributed within the update cycle. This may not be a desirable condition during Shuttle launch or landing operations and deserves further investigation. Although this potential problem is of concern, it is likely that a concept of operation for Shuttle launches and landings could be devised (e.g., limit special one-time product requests, use special launch / landing routine products set (RPS) lists, and limit access to dial-up lines during Shuttle launch / landing operations) which would mitigate this potential problem.

Although not part of this investigation, another item of particular interest to the weather community which is related to weather radars is the utility and need for dual-Doppler capability. Dual-Doppler coverage would significantly enhance the weather community's ability to accurately describe the real-time three-dimensional mesoscale structure of the atmosphere in the KSC / CCAS region and would be valuable input to mesoscale numerical weather prediction models currently being developed and transitioned for operations use. These improved capabilities would ultimately result in enhanced safety and more launch / landing availability for the Shuttle. This will be particularly important in the upcoming regime of 5-minute Shuttle launch windows.

5.0 Summary and Recommendations

5.1 Summary of Scan Strategy Comparison

This investigation compared the beam coverage patterns of the WSR-74C / McGill radar located at PAFB and the WSR-88D radar using VCP 11 located at the Melbourne NWS Office relative to the area of concern for weather FR and LCC evaluations. The analysis focused on beam coverage within four vertical 74 km radius cylinders (1 to 4 km AGL, 4 to 8 km AGL, 8 to 12 km AGL, and 1 to 12 km AGL) centered on Launch Complex 39A. Key characteristics of the two radars' beam coverage are summarized in Table 5.1.

This analysis has shown that effective beam coverage is a function of both scan strategy and distance from the radar to the point of interest. For example, the results indicate that the advantages inherent in the scan strategy of the McGill radar (i.e., more elevation scans and higher elevation scans) relative to the WSR-88D are offset by the preferred location of the WSR-88D relative to the McGill radar and KSC / CCAS. Indeed, the beam coverage of the WSR-88D exceeds the beam coverage of the McGill radar over most of the KSC / CCAS area by 5 to 20% in the 4 to 8 km layer, by 5 to 10% in the 8 to 12 km layer, and by 5 to 10% in the 1 to 12 km layer.

The beam coverage of the scan strategy employed by the McGill radar and the VCP 11 scan strategy of the WSR-88D exceeds 70% in the 1 to 4 km, 4 to 8 km, and 1 to 12 km layers for most of the area of concern. However, the extent of good beam coverage (coverage equal to or greater than 70%) is less in the 8 to 12 km layer for both radars because of the gaps in radar beam coverage in the higher elevation scans. Indeed, neither radar provides good beam coverage in the 8 to 12 km layer over most of the KSC / CCAS area.

The difference in percent of the atmosphere sampled between the two radars is less than 10% for more than half of the area of concern for all four layers. However, there are significant differences in beam coverage between the two radars in the near vicinity of the radars. This is a result of the cone of silence directly above and near the radars which is a function of the radar's scan strategy. This limitation is slightly more severe for the WSR-88D since the highest elevation angle of VCP 11 is 19.51° whereas the highest elevation angle of the McGill scan strategy is 35.97° . For all four layers, the McGill radar provides better beam coverage than the WSR-88D radar at and in a small region to the south-southwest of the WSR-88D radar. Conversely, the WSR-88D radar provides better beam coverage than the McGill radar at and in a small region to the north-northeast of the McGill radar.

**Table 5.1. Key Characteristics of the McGill and WSR-88D
Radars' Beam Coverage**

Layer of the Atmosphere	Beam Coverage of the PAFB WSR/74C / McGill Radar and the Melbourne WSR-88D Radar
1 to 4 km above ground level	<p>Radar beam coverage exceeds 90% for both of the radars for the majority of the area within the region of concern.</p> <p>The difference in beam coverage between the two radars is less than 10% for most of the region of concern.</p> <p>The McGill radar's beam coverage exceeds the WSR-88D radar's beam coverage by 10 to 60% in the extreme southern portion of the region of concern.</p> <p>The WSR-88D radar's beam coverage exceeds the McGill radar's beam coverage by 5 to 40% in the region extending from the McGill radar site to Cape Canaveral.</p>
4 to 8 km above ground level	<p>Radar beam coverage exceeds 70% for both of the radars for the majority of the area within the region of concern.</p> <p>Radar beam coverage exceeds 90% for both of the radars for almost all of the northern half of the region of concern.</p> <p>The difference in beam coverage between the two radars is less than 10% for most of the region of concern.</p> <p>The McGill radar's beam coverage exceeds the WSR-88D radar's beam coverage by 10 to 50% in the extreme southern portion of the region of concern.</p> <p>The WSR-88D radar's beam coverage exceeds the McGill radar's beam coverage by 5 to 20% in the region extending from the McGill radar site to Cape Canaveral and Merritt Island.</p>
8 to 12 km above ground level	<p>Radar beam coverage exceeds 70% for both of the radars for most all of the area within the northern half of the region of concern.</p> <p>Radar beam coverage is less than 70% for both radars for most all of the KSC / CCAS region.</p> <p>The difference in beam coverage between the two radars is less than 10% for more than half of the region of concern.</p> <p>The McGill radar's beam coverage exceeds the WSR-88D radar's beam coverage by 10 to 40% in the extreme southern portion of the region of concern.</p> <p>The WSR-88D radar's beam coverage exceeds the McGill radar's beam coverage by 5 to 10% in the region extending from the McGill radar site to Cape Canaveral and Merritt Island.</p>
1 to 12 km above ground level	<p>Radar beam coverage exceeds 70% for both of the radars for the majority of the area within the region of concern.</p> <p>The difference in beam coverage between the two radars is less than 10% for more than half of the region of concern.</p> <p>The McGill radar's beam coverage exceeds the WSR-88D radar's beam coverage by 10 to 40% in the extreme southern portion of the region of concern.</p> <p>The WSR-88D radar's beam coverage exceeds the McGill radar's beam coverage by 5 to 20% in the region extending from the McGill radar site to Cape Canaveral and Merritt Island.</p>

5.2 Conclusions and Recommendations

The results of this investigation indicate that the beam coverage of the WSR-88D using VCP 11 located at the Melbourne NWS Office is comparable (difference in percent of the atmosphere sampled between the two radars is 10% or less) within the area of concern to the beam coverage of the WSR-74C / McGill radar located at PAFB. Both radars provide good beam coverage over much of the atmospheric region of concern. In addition, both radars provide poor beam coverage (coverage less than 50%) over limited regions near the radars due to the radars' cone of silence and gaps in coverage within the higher elevation scans. In conclusion, based on an analysis of scan strategy alone, the WSR-88D located at Melbourne NWS Office could be used to perform the essential functions now performed by the PAFB WSR-74C / McGill radar for evaluating Shuttle weather FR and LCC.

It is important to note there are other characteristics of the two radars that should be considered in the process of determining if the WSR-88D located at the Melbourne NWS Office could be used to perform the essential functions now performed by the PAFB WSR-74C / McGill radar for evaluating Shuttle weather FR and LCC. A partial list of additional radar system characteristics which deserve consideration include:

- Radar digitizers
- Radar side lobe patterns
- Ability and cost of customizing radar system capabilities (i.e., VSR0C)
- Ease of use of system
- Life cycle costs
- Other system limitations (e.g. load shedding by the WSR-88D).

Although not part of this investigation, another item of particular interest to the weather community which is related to weather radars is the utility and need for dual-Doppler capability. Dual-Doppler coverage would significantly enhance the weather community's ability to accurately describe the real-time three-dimensional mesoscale structure of the atmosphere in the KSC / CCAS region and would be valuable input to mesoscale numerical weather prediction models currently being developed and transitioned for operations use. These improved capabilities would ultimately result in enhanced safety and more launch / landing availability for the Shuttle. This will be particularly important in the upcoming regime of 5-minute Shuttle launch windows.

One means of achieving dual-Doppler coverage of the KSC / CCAS region would be to re-locate the PAFB WSR-74C / McGill radar to the northwest of KSC and upgrade it to include Doppler capabilities. Re-locating the WSR-74C / McGill radar to the northwest of KSC would also improve the combined radar beam coverage within the area of concern (i.e., the McGill radar would provide good coverage over the WSR-88D's cone of silence and vice versa).

6.0 References

R.J. Doviak and D.S. Zmic, 1993: *Doppler Radar and Weather Observations*. Academic Press, Inc., 562 pp.

Johnson Space Center, 1992: *Johnson Space Center Flight Rules*, paragraph 4-64(A), page 4-51.

Appendix A

Procedures for Modifying WSR-88D Scan Strategies

The WSR88D located at the Melbourne NWS Office currently has two approved precipitation scan strategies, the precipitation/severe weather scan (VCP 11) and the alternative precipitation scan (VCP 21). It is possible for the Shuttle weather community to make requests to modify either of the two approved precipitation scan strategies or to make a request for a new precipitation scan strategy. This request can be a new / modified scan strategy for the Melbourne WSR-88D radar only or for the Melbourne WSR-88D radar as well as other WSR-88D radars. The following steps summarize the request submission process and scan strategy request limitations.

- Draft a letter defining the new proposed scan strategy or the modification to the existing scan strategy. This letter should include benefits and impacts and should be given to the local NWS Point-of-Contact (POC) (the Meteorologist-In-Charge at the Weather Service Office at Melbourne, Florida). Alternatively, the letter could be submitted to the local Air Force POC.
- The local POC then sends the request to the agency POC for Change Requests. The local POC may reword the request if clarification is necessary and may or may not include a letter supporting the change request.
- The change request is then subjected to an engineering review to determine scan strategy suitability. The change request and the results of the engineering review are then submitted to the NEXRAD Technical Advisory Committee (TAC). If the request is approved by the TAC, then the change is implemented in the next software update (software updates typically occur annually).

The following is a list of items which should be considered when proposing a modification to an existing scan strategy or proposing a new scan strategy for the WSR-88D.

- The modified / new scan strategy should not have more than 14 elevations scans because of processing load impacts.
- The upper limit for an elevation scan is 45°.
- The processing load resulting from the modified / new scan strategy must be such that the update rate would be 6 minutes or less.

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<p>The objective of this investigation is to determine whether the current standard WSR-88D radar (NEXRAD) scan strategies permit the use of the Melbourne WSR-88D to perform the essential functions now performed by the Patrick Air Force Base (PAFB) WSR-74C / McGill radar for evaluating Shuttle weather Flight Rules (FR) and Launch Commit Criteria (LCC). To meet this objective, the investigation compared the beam coverage patterns of the WSR-74C / McGill radar located at PAFB and the WSR-88D radar located at the Melbourne National Weather Service (NWS) Office over the area of concern for weather FR and LCC evaluations. The analysis focused on beam coverage within four vertical 74 km radius cylinders (1 to 4 km above ground level (AGL), 4 to 8 km AGL, 8 to 12 km AGL, and 1 to 12 km AGL) centered on Kennedy Space Center (KSC) Launch Complex 39A. The PAFB WSR-74C / McGill radar is approximately 17 km north-northeast of the Melbourne WSR-88D radar.</p> <p>The beam coverage of the WSR-88D using VCP 11 located at the Melbourne NWS Office is comparable (difference in percent of the atmosphere sampled between the two radars is 10% or less) within the area of concern to the beam coverage of the WSR-74C / McGill radar located at PAFB. Both radars provide good beam coverage over much of the atmospheric region of concern. In addition, both radars provide poor beam coverage (coverage less than 50%) over limited regions near the radars due to the radars' cone of silence and gaps in coverage within the higher elevation scans. Based on scan strategy alone, the WSR-88D radar could be used to perform the essential functions now performed by the PAFB WSR-74C / McGill radar for evaluating Shuttle weather FR and LCC. Other radar characteristics may, however, affect the decision as to which radar to use in a given case.</p>			
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